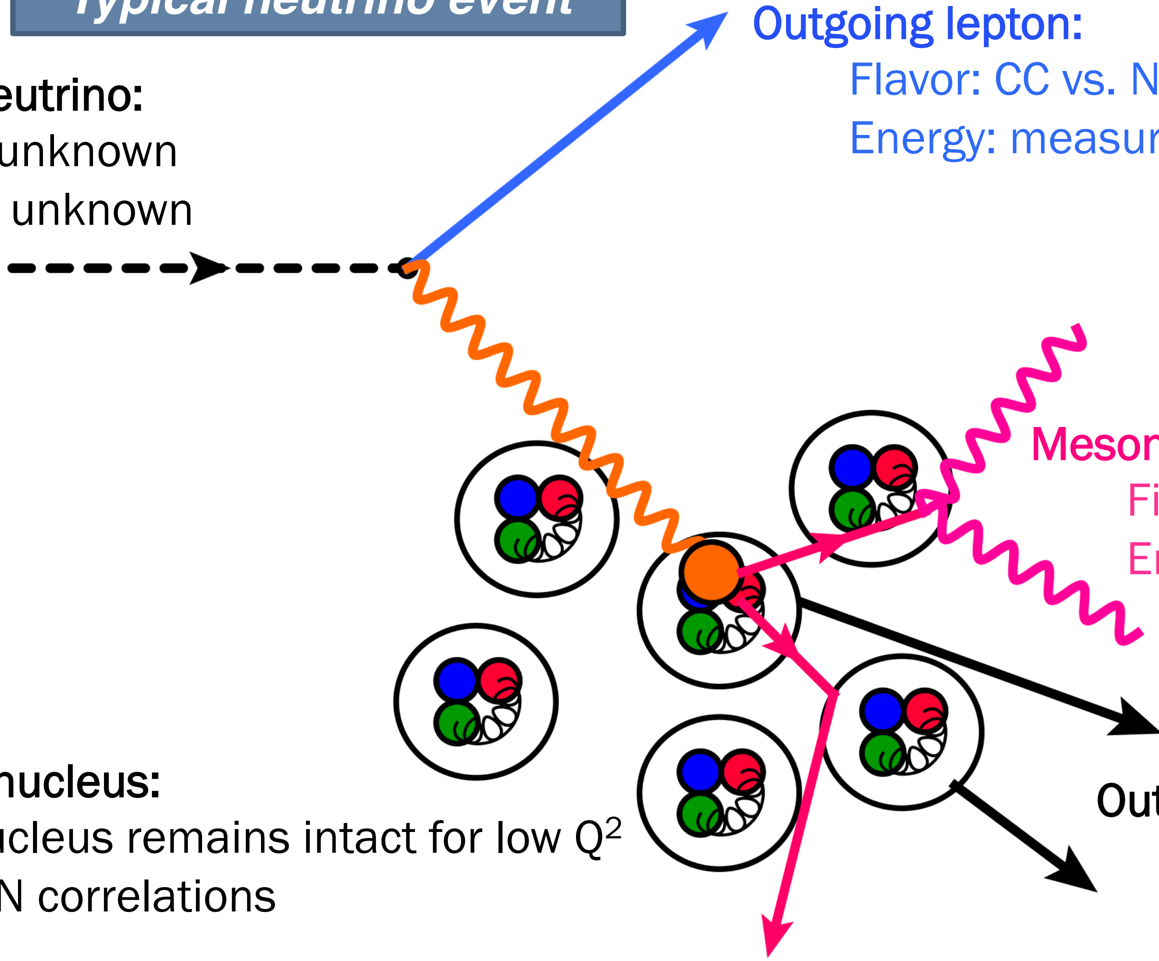
LArIAT Reconstruction Assessment

Jen Raaf, for the LArIAT Collaboration

LARIAT MOTIVATION: NEEDS OF NEUTRINO EXPTS

In neutrino experiments, try to determine flavor and estimate energy of incoming neutrino by looking at outgoing products of the interaction.

Typical neutrino event



Incoming neutrino:

Flavor unknown

Energy unknown

Outgoing lepton:

Flavor: CC vs. NC, μ^+ vs. μ^-, e vs. γ

Energy: measure

Mesons:

Final State Interactions

Energy? Identity?

Target nucleus:

Nucleus remains intact for low Q^2

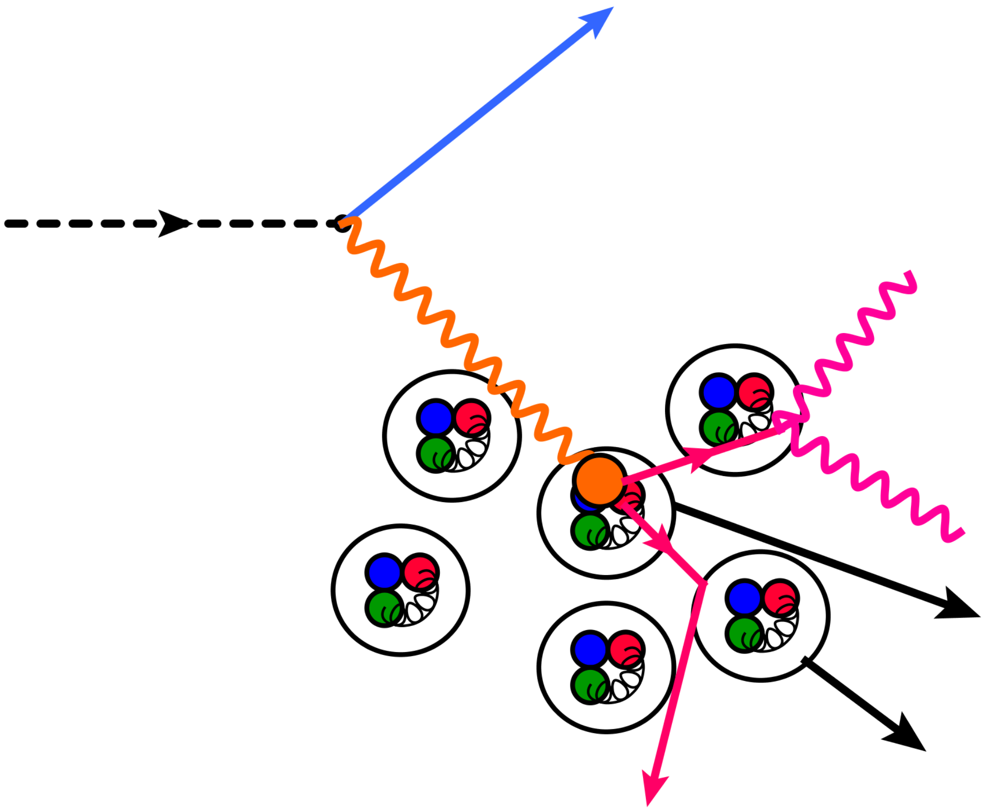
N-N correlations

Outgoing nucleons:

Visible? Energy?

LARIAT MOTIVATION: NEEDS OF NEUTRINO EXPTS

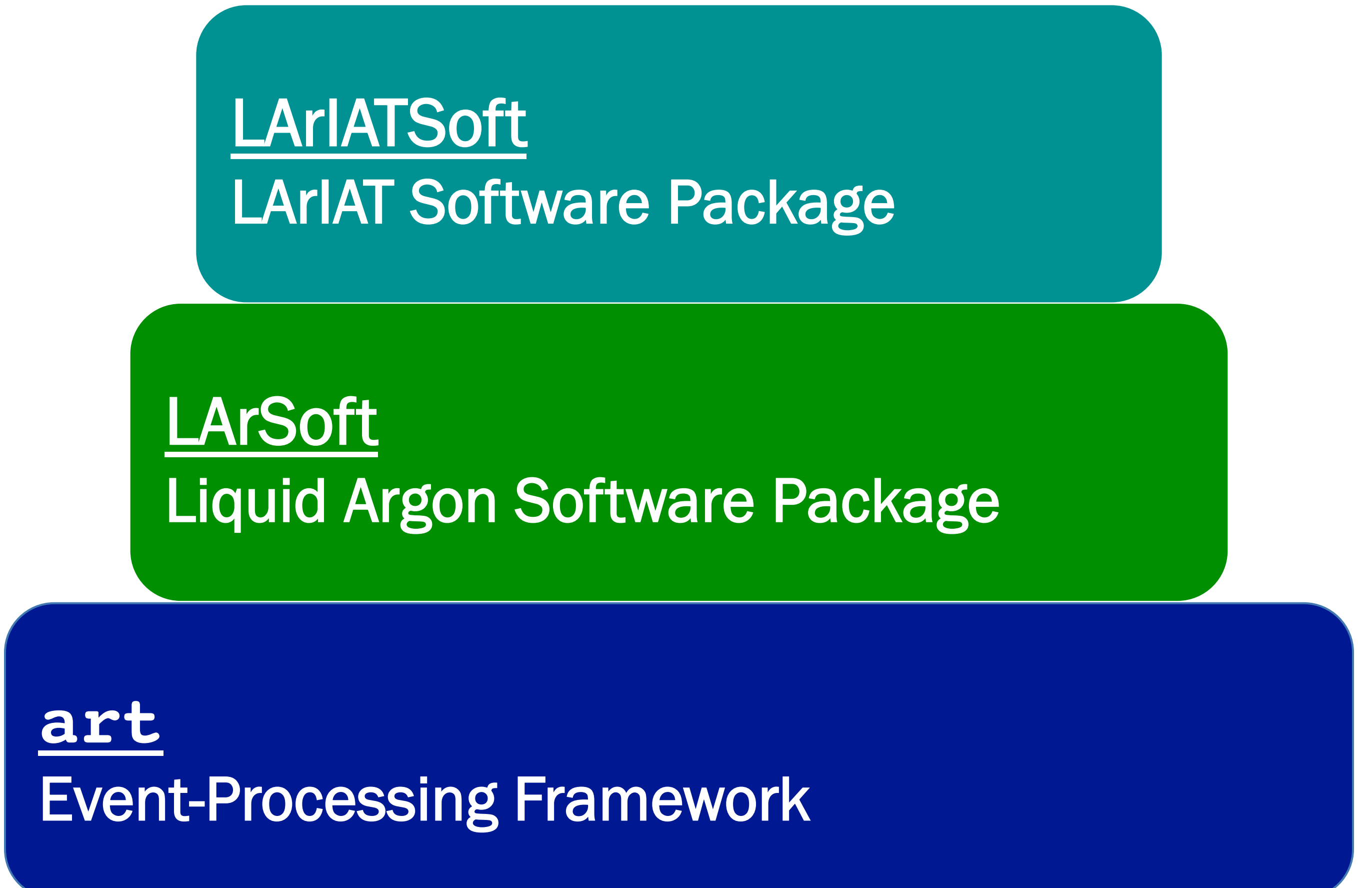
LArIAT studies the types of particles that are the *products* of neutrino experiments, in order to better understand how well we can identify them and estimate their energies. *Trigger conditions and auxiliary detectors are different than in neutrino experiments.*



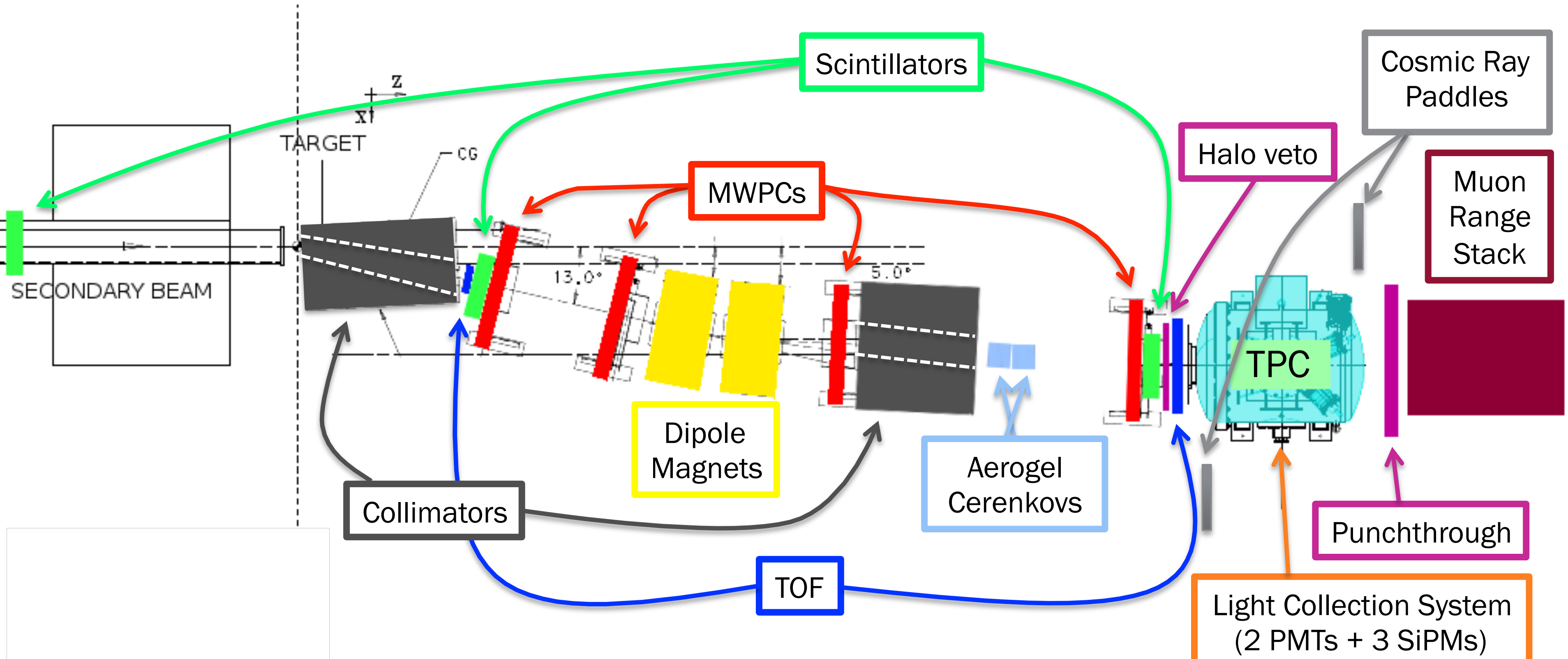
- Visible energy calibration
- Calorimetric response and resolution
- Particle identification
- Event reconstruction
- Hadron-argon scattering cross sections

INFRASTRUCTURE

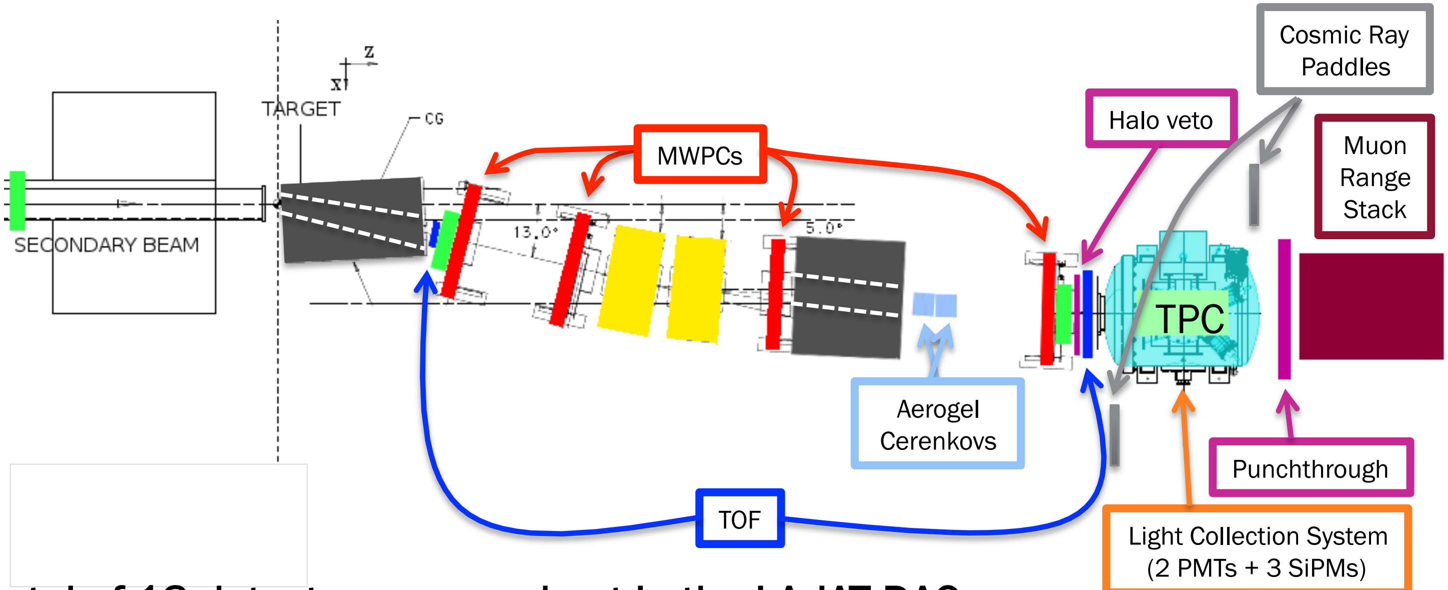
- LArIAT's data acquisition system (DAQ) is built using the **art** framework
- Output products of artDAQ are turned into LArSoft-readable objects
- LArSoft and LArIATsoft modules/algorithms analyze LArSoft objects



LARIAT BEAMLINE



RAW DATA FROM MANY TYPES OF DEVICES



A total of 18 detectors are read out in the LArIAT DAQ

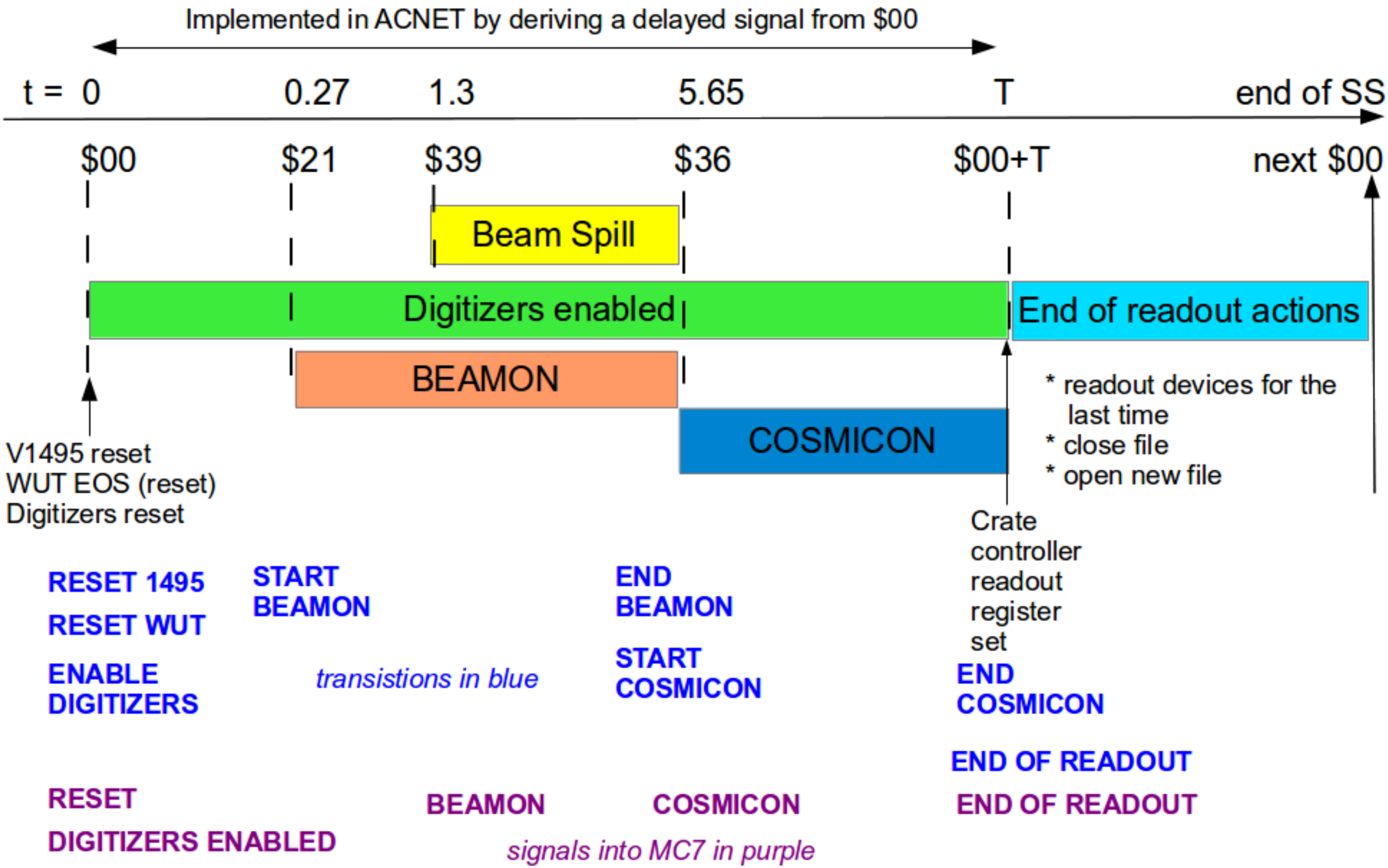
- 2 Time of Flight (TOF) detectors (upstream & downstream)
- 4 Multi-Wire Proportional Chambers (MWPCs) for momentum and tracking measurements along beamline
- 2 Aerogel Cherenkov detectors (pion/muon tagging & ID)
- 2 beamline scintillators (Halo veto + Punchthrough)
- 5 Light Collection System detectors (2 PMTs + 3 SiPMs)
- 1 LArTPC (480 wire channels)
- 2 Cosmic Ray Stands (near top and bottom of TPC, each with 4+1 scint paddles)
- 1 Muon Range Stack (made of 16 scintillator paddles)

DETECTORS AND READOUT

Readout system	Detector	Channels	DAQ fragment → LArSoft Digit
CAEN v1740 64-channel digitizer (128 ns/sample)	TPC wires	480	CAENFragment → RawDigit
	Muon Range Stack	16	CAENFragment→ AuxDetDigit
	Trigger inputs	16	CAENFragment→ TrigDigit
CAEN v1751 8-channel digitizer (1 ns/sample)	TPC light collection system (2 PMTs + 3 SiPMs)	5	CAENFragment→ OpDetPulse
	TOF PMTs	4	CAENFragment→ OpDetPulse
	Aerogel PMTs	4	CAENFragment→ OpDetPulse
	Aerogel Cosmic PMT	1	CAENFragment→ OpDetPulse
	Beam halo PMTs	2	CAENFragment→ OpDetPulse
MWPC controller (1.17 ns/sample)	MWPC TDCs	16X64	TDCFragment→ AuxDetDigit

- Each subsystem outputs LArIAT-specific fragments
- For each spill, all LArIAT-specific fragments are wrapped into one LariatFragment
  NB: Fragments are asynchronous at readout, synchronized later offline
- Fragments are converted to LArSoft “digits” after synchronization

LARIAT SUPERCYCLE



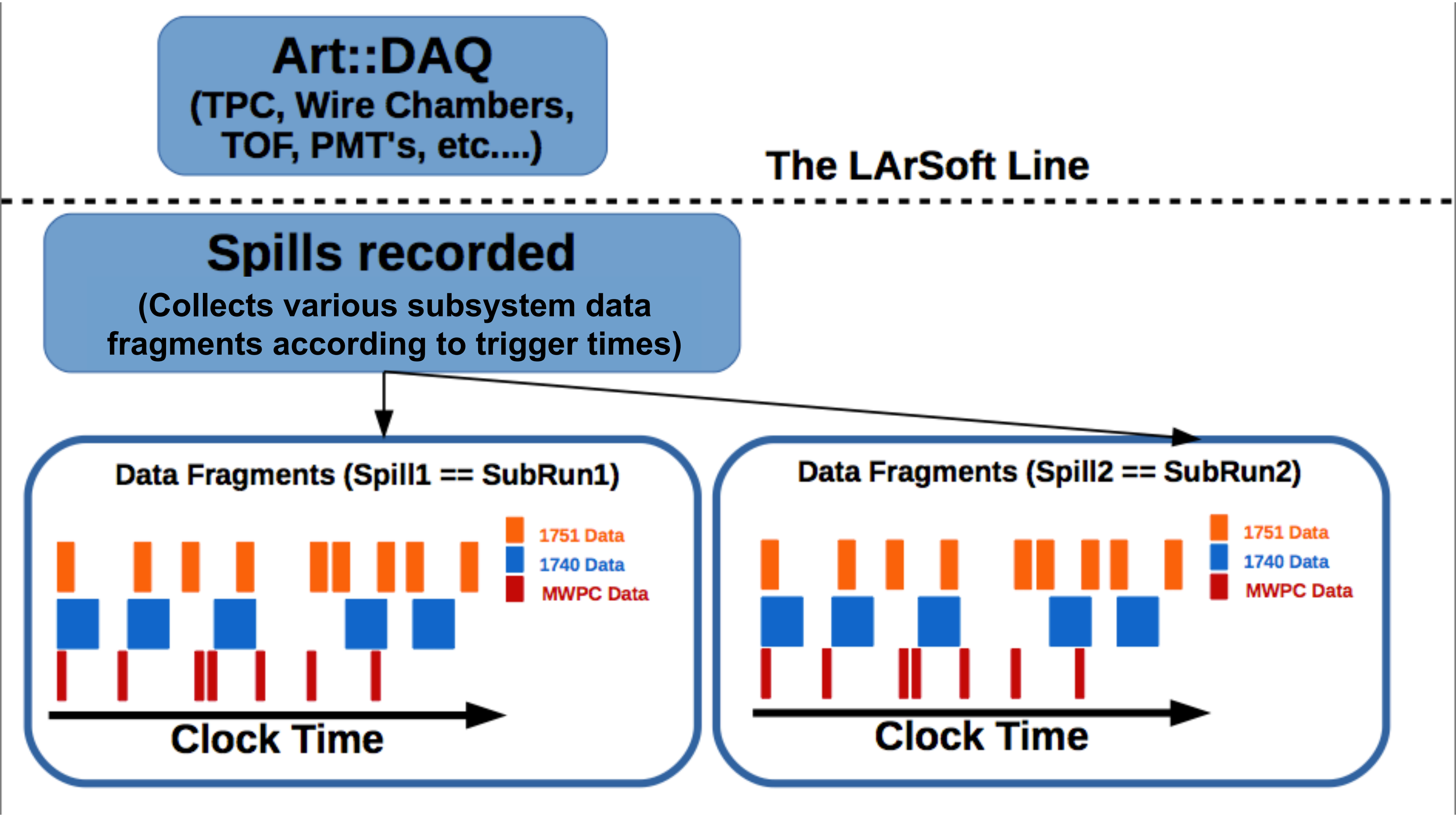
LARIAT READOUT

- At data collection time, a sensible unit for LArIAT readout is one beam spill (which is also called one subrun)
  - 4.2 second beam-on + 26 second cosmic-on period

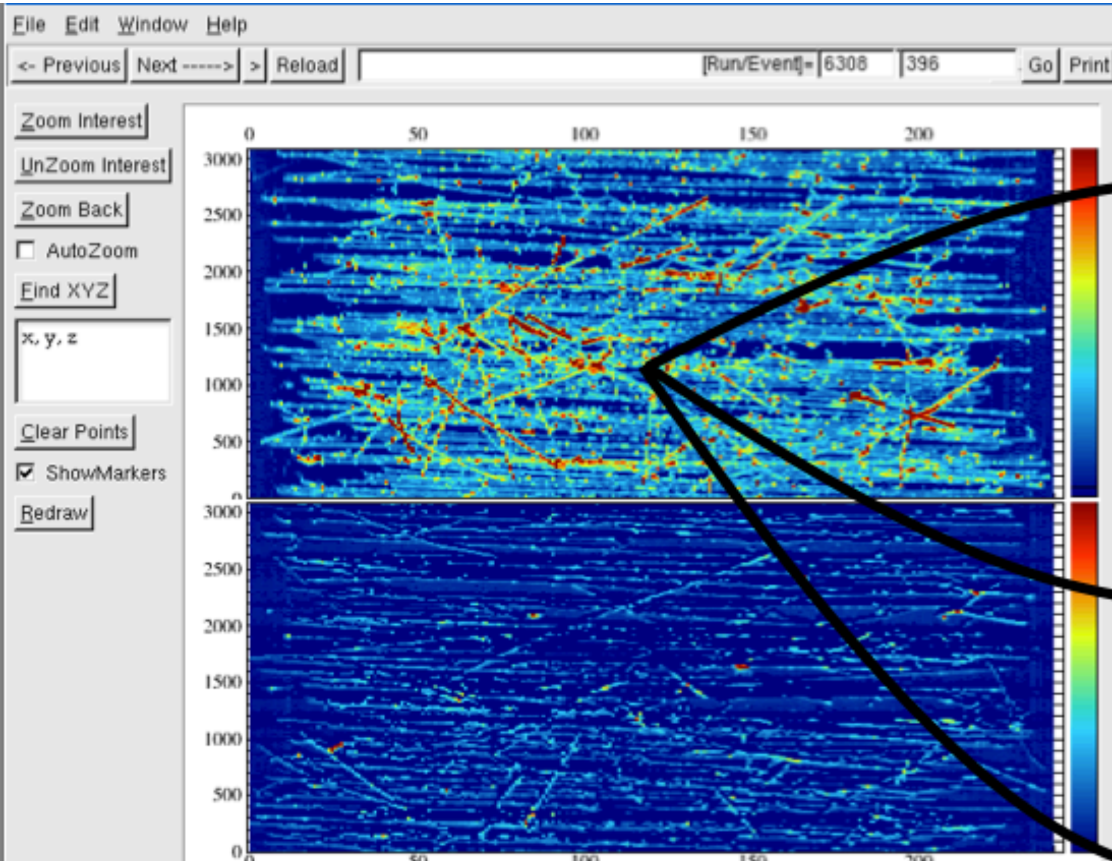
    350 usec TPC drift window → multiple drift windows per spill
  - Collect up to 200 triggers per spill (average ~30-40)

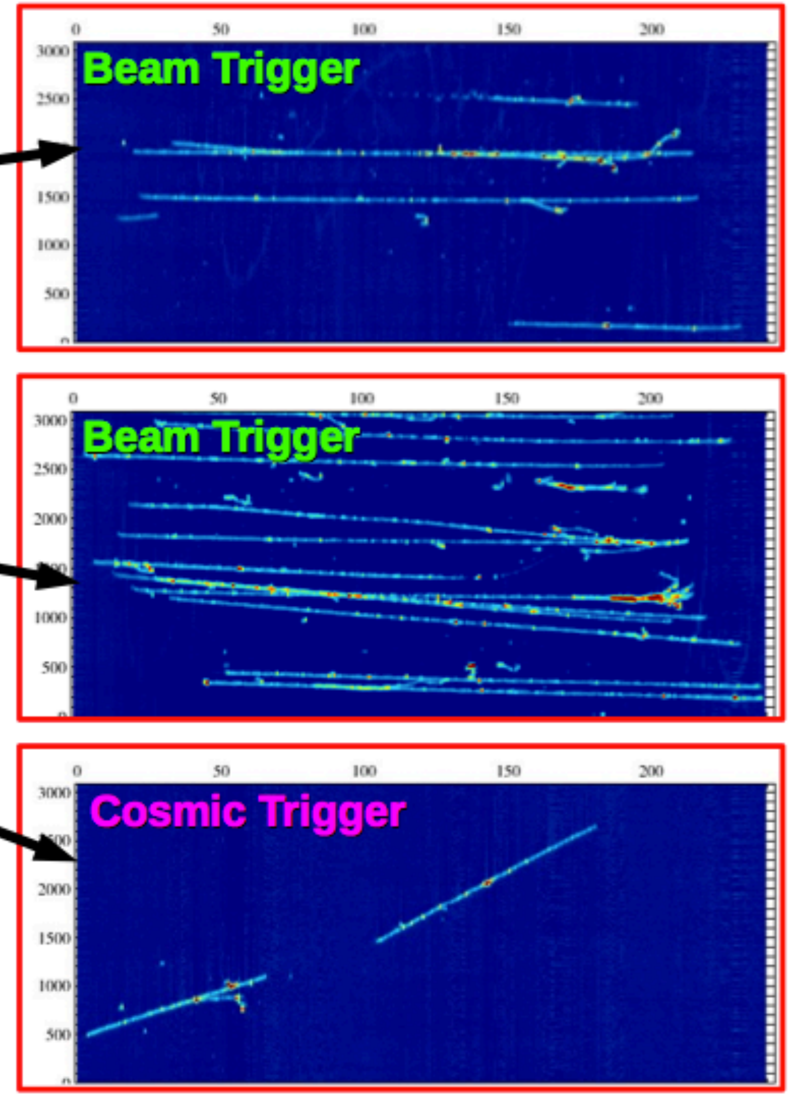
    Each trigger is a predefined condition that causes readout of all systems
- Each readout system has its own clock; we have prompt and delayed triggers
  - Delayed trigger goes to TPC at end of drift window
  - Synchronize every spill via reset at $00

RAW DATA STRUCTURE



RAW DATA STRUCTURE

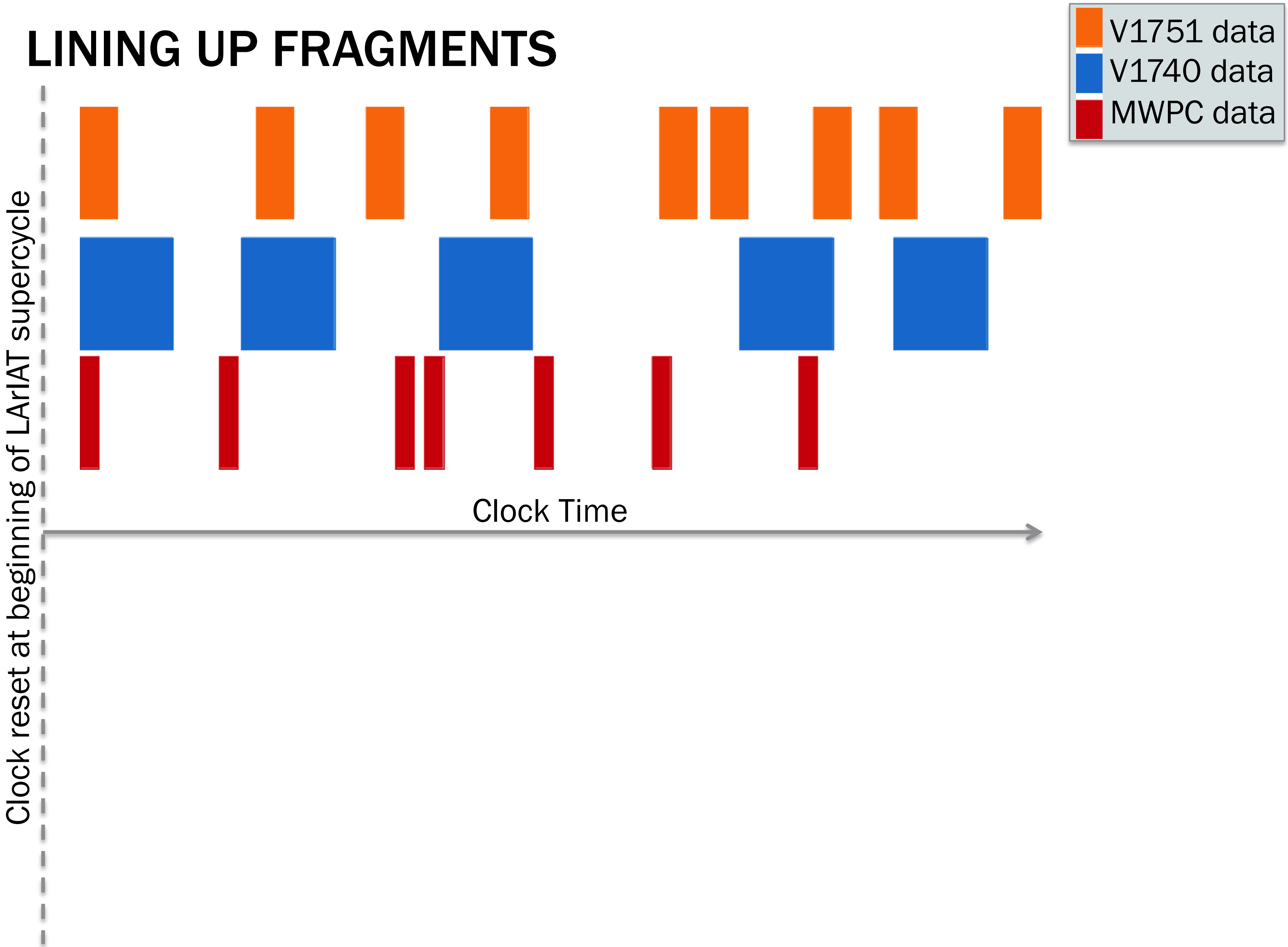




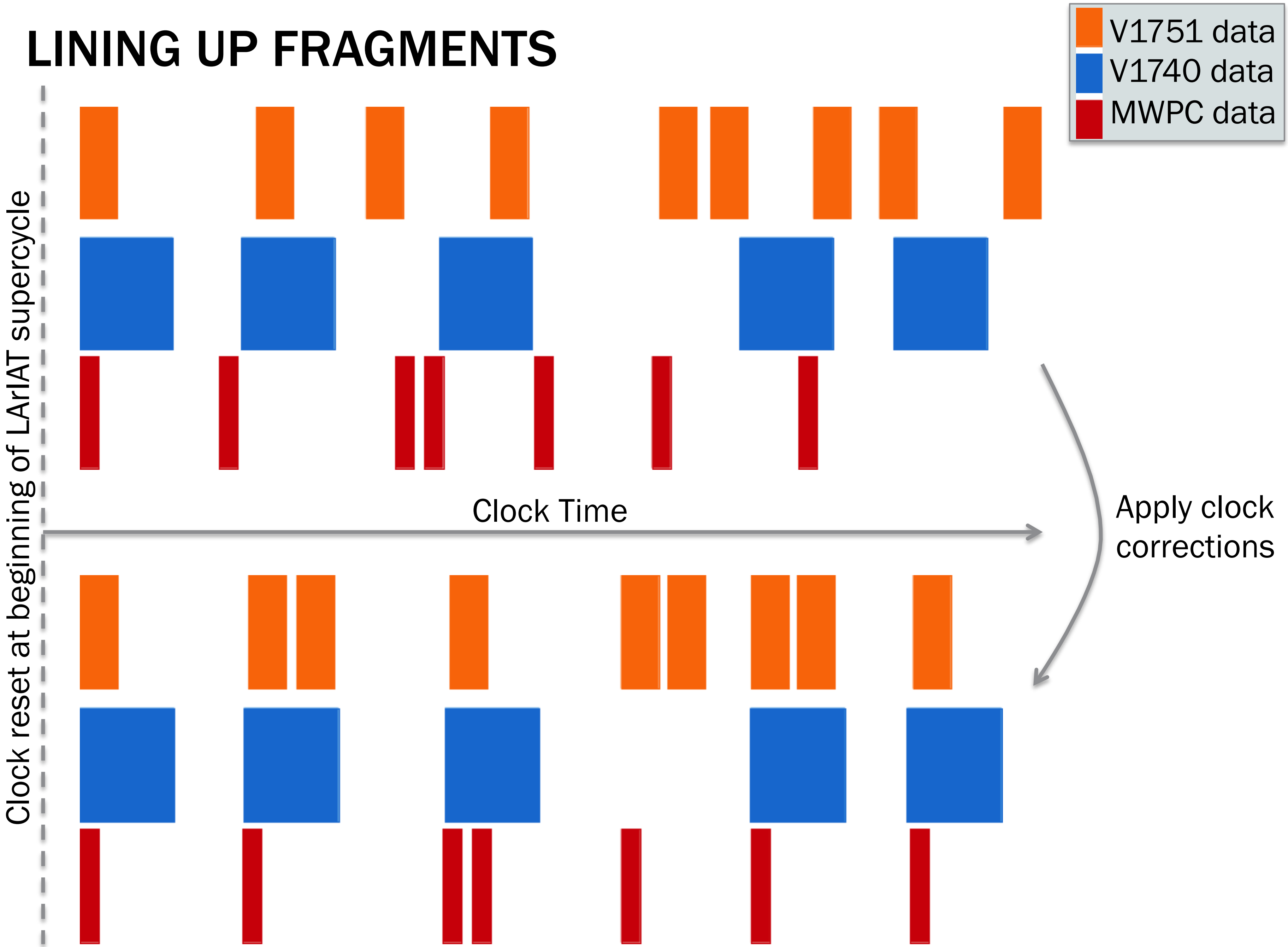
There are 40 different "triggers" within this one "data block"!

In order to make sense of this with LArIATsoft we want to restructure the data

LINING UP FRAGMENTS



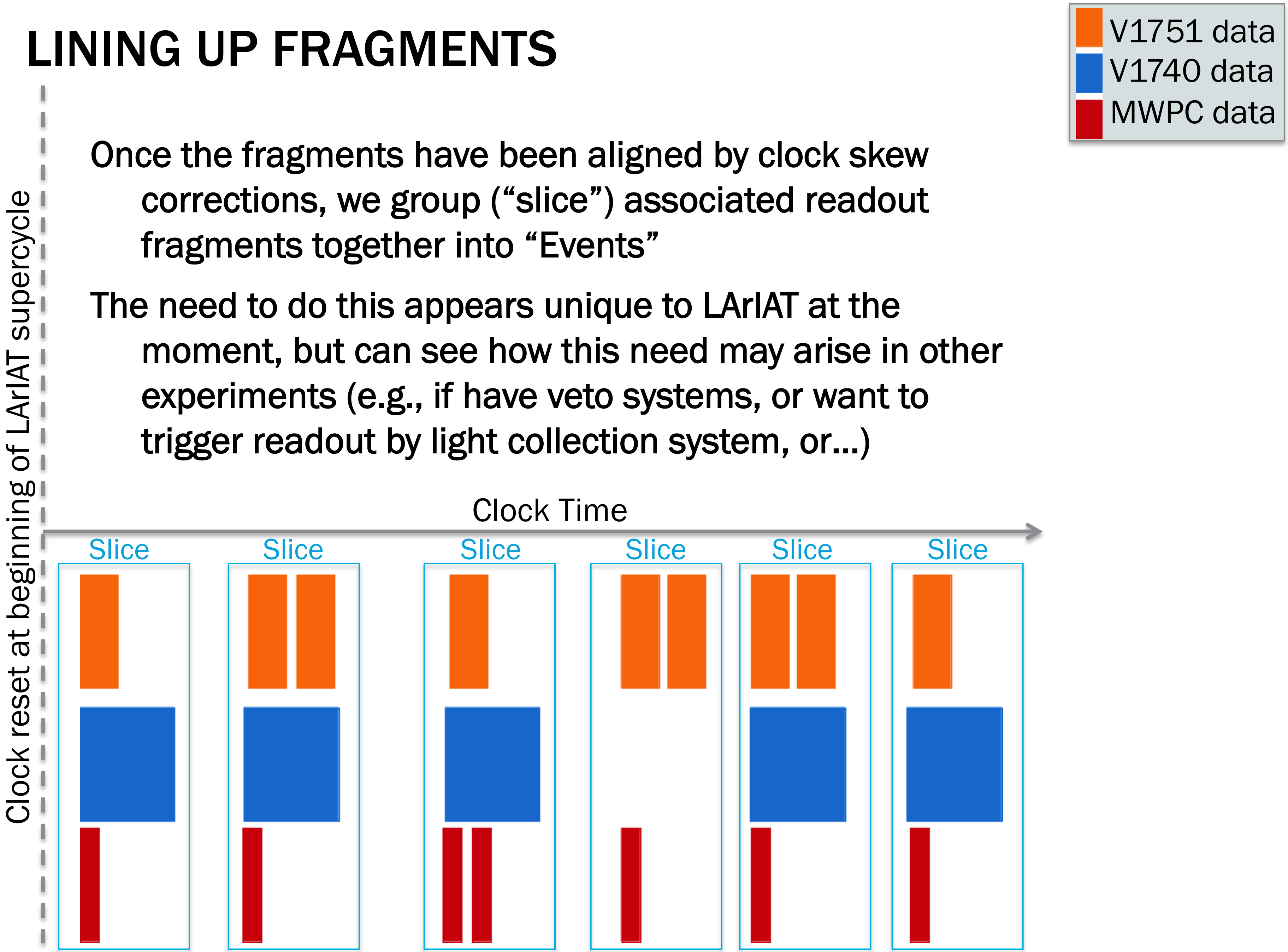
LINING UP FRAGMENTS



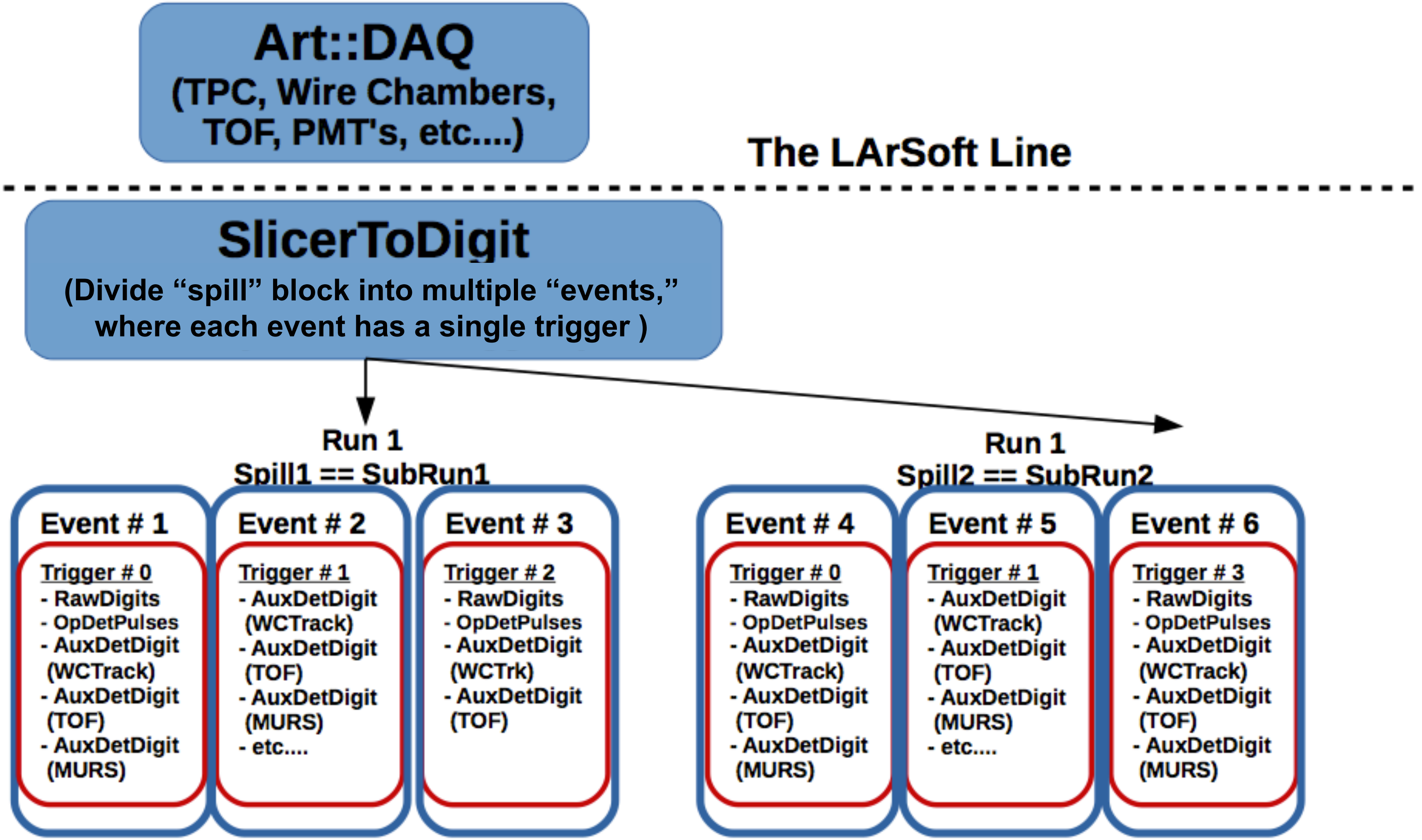
LINING UP FRAGMENTS

Once the fragments have been aligned by clock skew corrections, we group ("slice") associated readout fragments together into "Events"

The need to do this appears unique to LArIAT at the moment, but can see how this need may arise in other experiments (e.g., if have veto systems, or want to trigger readout by light collection system, or...)



RAW DATA STRUCTURE



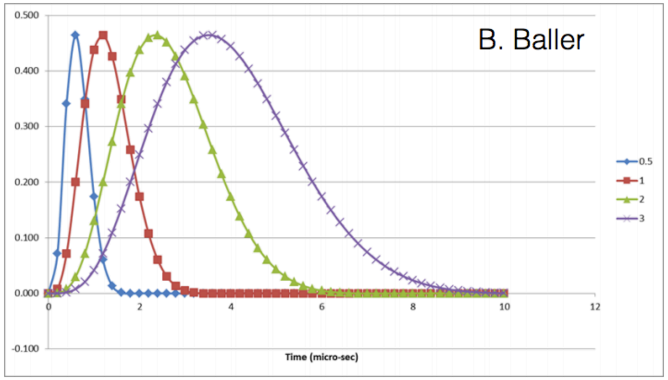
RECONSTRUCTING DATA

- **We use "standard" LArSoft reconstruction algorithms for TPC-based information, tuned for LArIAT**
  - TPC wire deconvolution, hit finding, clustering, track finding, shower reconstruction
- **For our light collection system:**
  - Simulations based off of MicroBooNE method (voxels)
  - Our system is novel (for neutrino-focused detectors, but has been used in dark matter detectors): reflector foil affixed to TPC walls, TPB wavelength shifter deposited on foil. PMTs and SiPMs see reflected light.
  - Just getting started with checking performance
- **For non-TPC systems (TOF, MWPC, Aerogel Cherenkov, Muon Range stack), we have written our own modules which take in the digits for these detectors and reconstruct objects based on the information**
  - MWPC tracks, TOF objects, Muon Range Stack hits, Aerogel hits
- **We can also put non-TPC object information together to form a preliminary particle ID hypothesis for objects entering the TPC**
  - Combine MWPC tracks and TOF to separate mu/pi from proton
  - Combine Aerogel and Muon Range stack to separate mu from pi

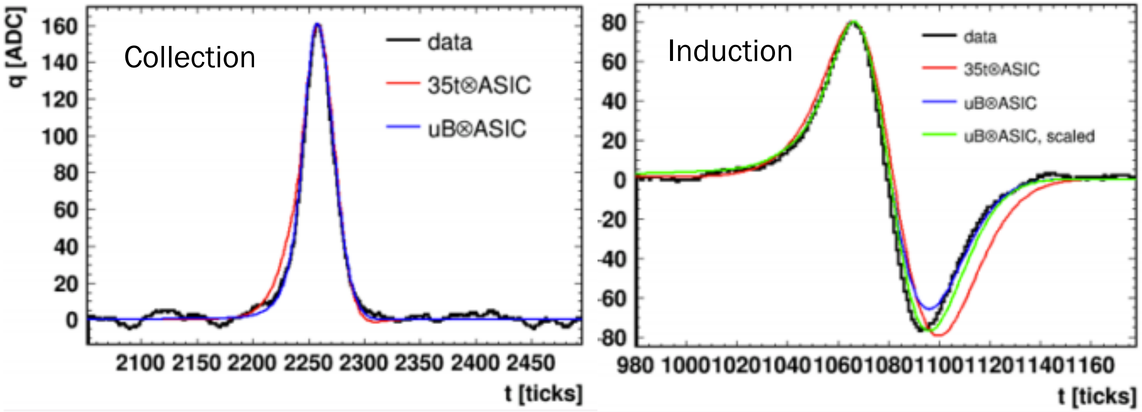
DECONVOLUTION

Remove effect of field response and electronics response by deconvolution

ASIC response



Field response



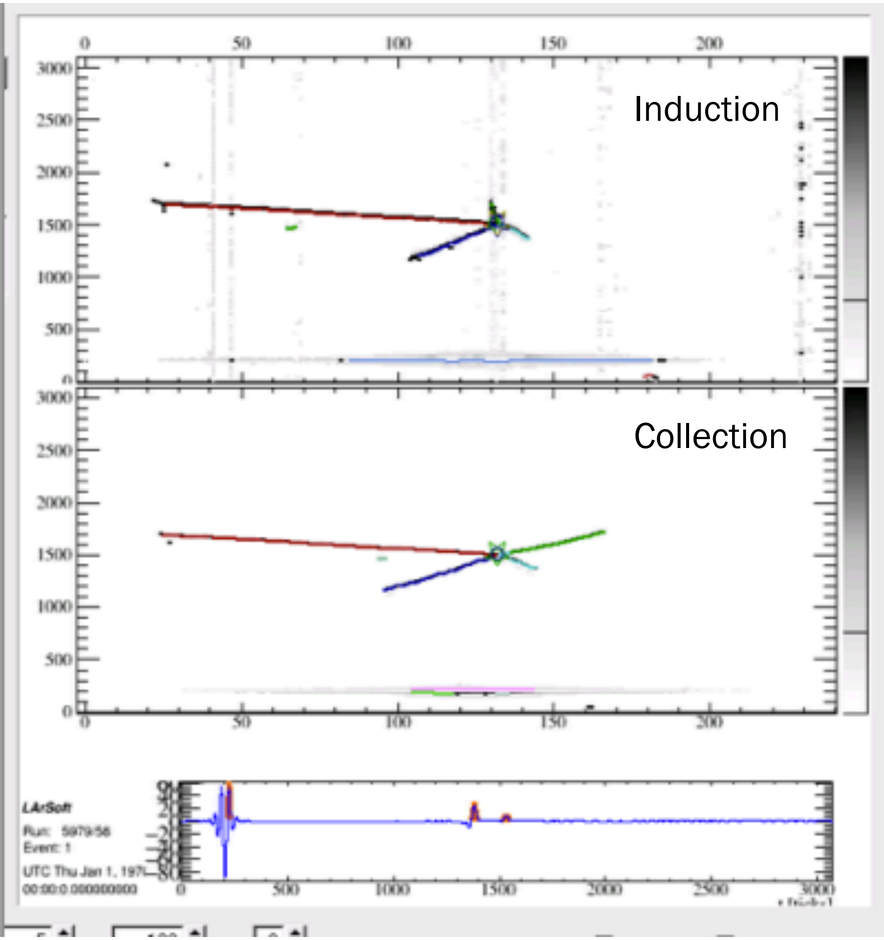
- BNL SPICE simulation of LArIAT (and uB) electronics in LArSoft
- Same pulse heights for different shaping times

- For LArIAT, use uB field response with a few tweaks

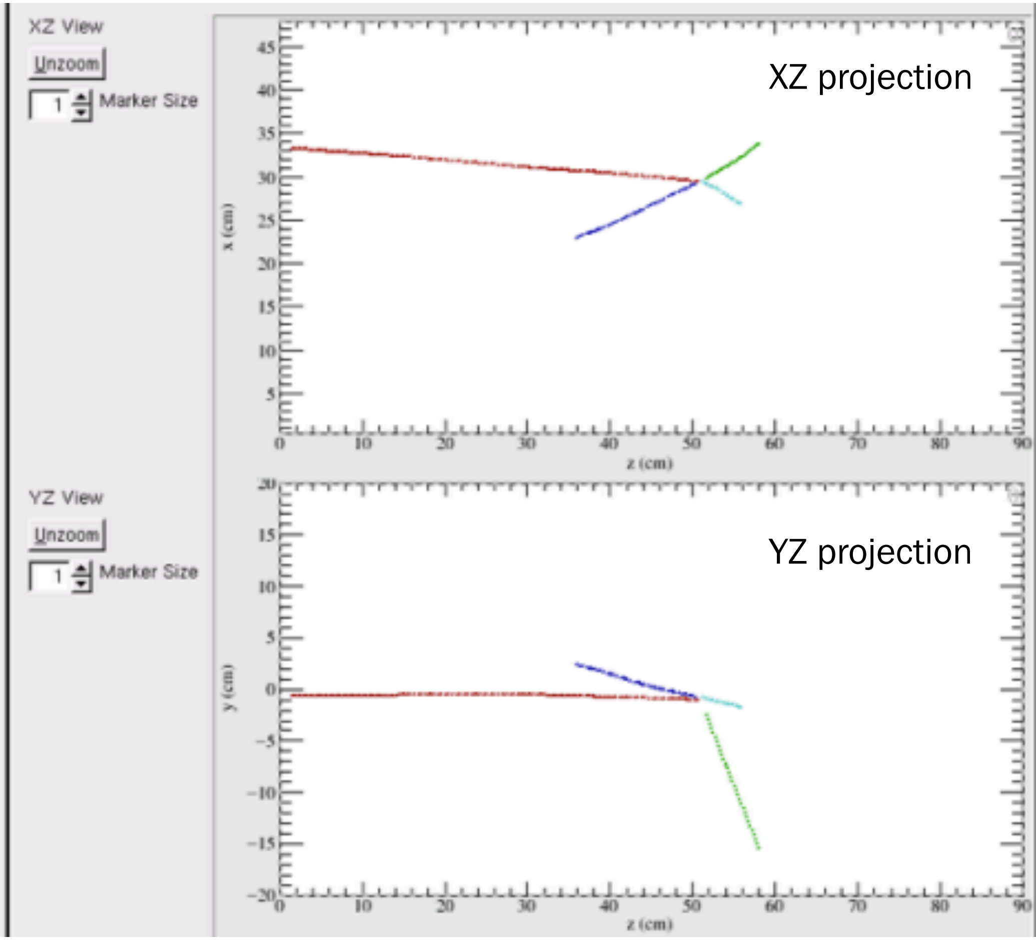
Tuning done so far works reasonably well, but some room for improvement.

TRACK RECONSTRUCTION: CLUSTER CRAWLER

2D reconstruction

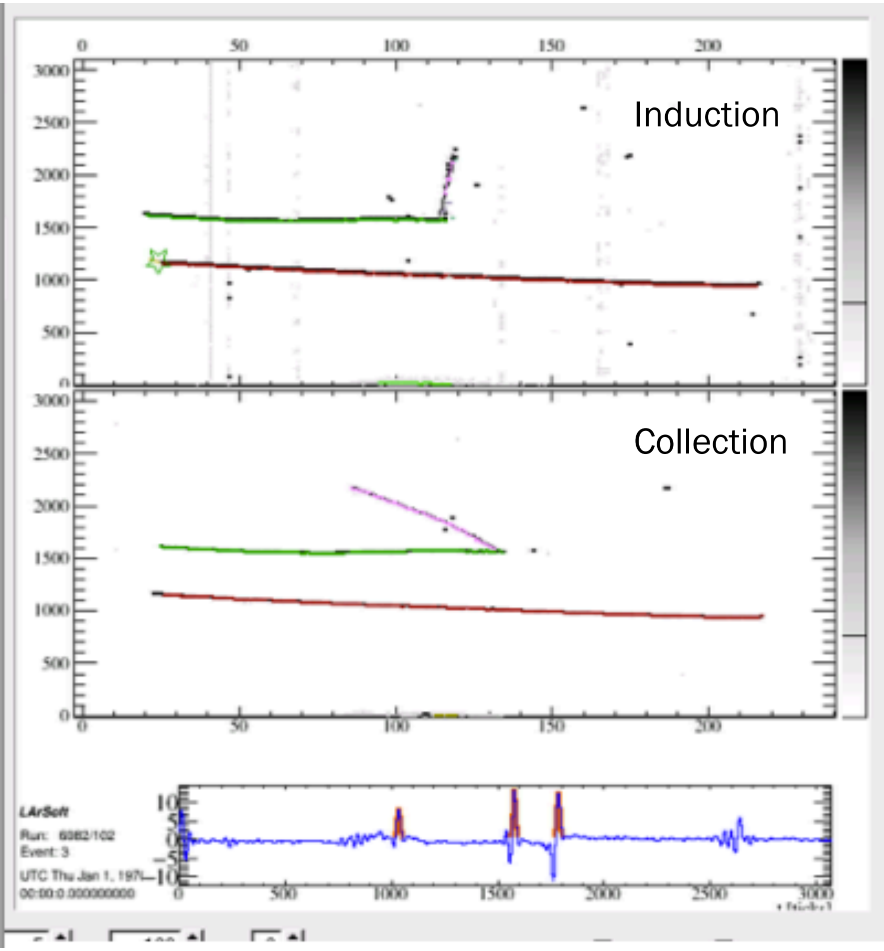


3D reconstruction

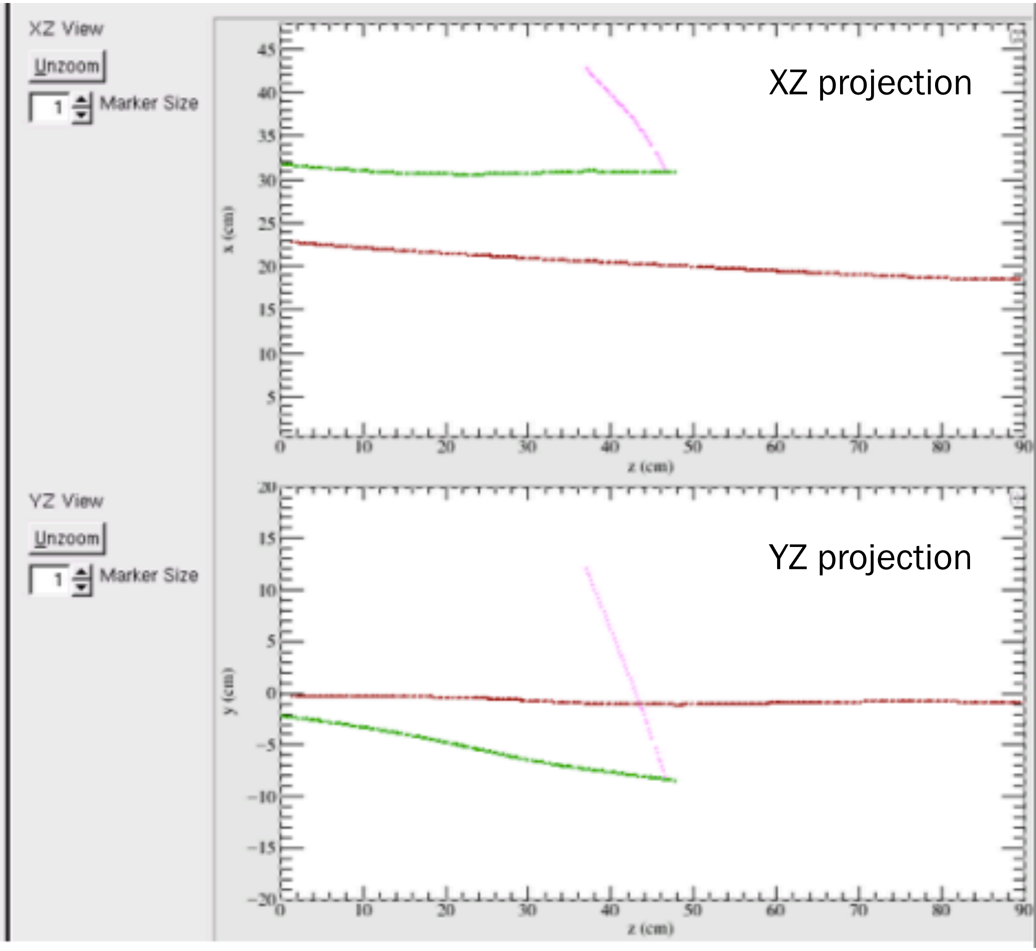


TRACK RECO: CLUSTER CRAWLER

2D reconstruction

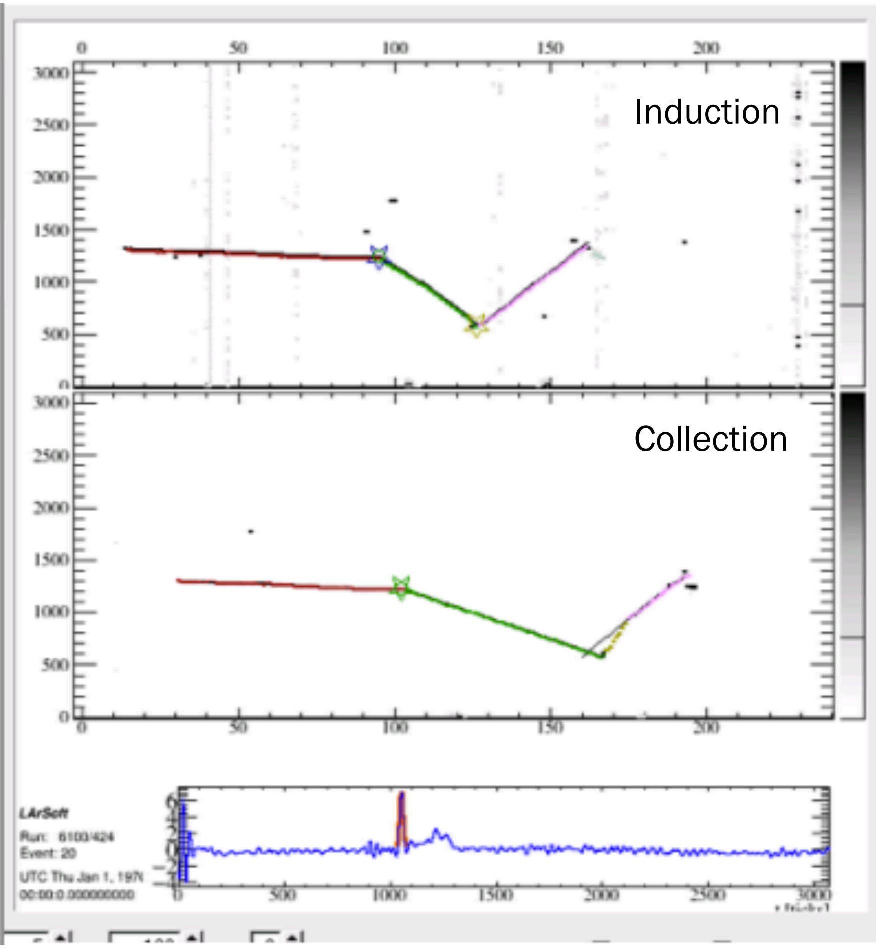


3D reconstruction

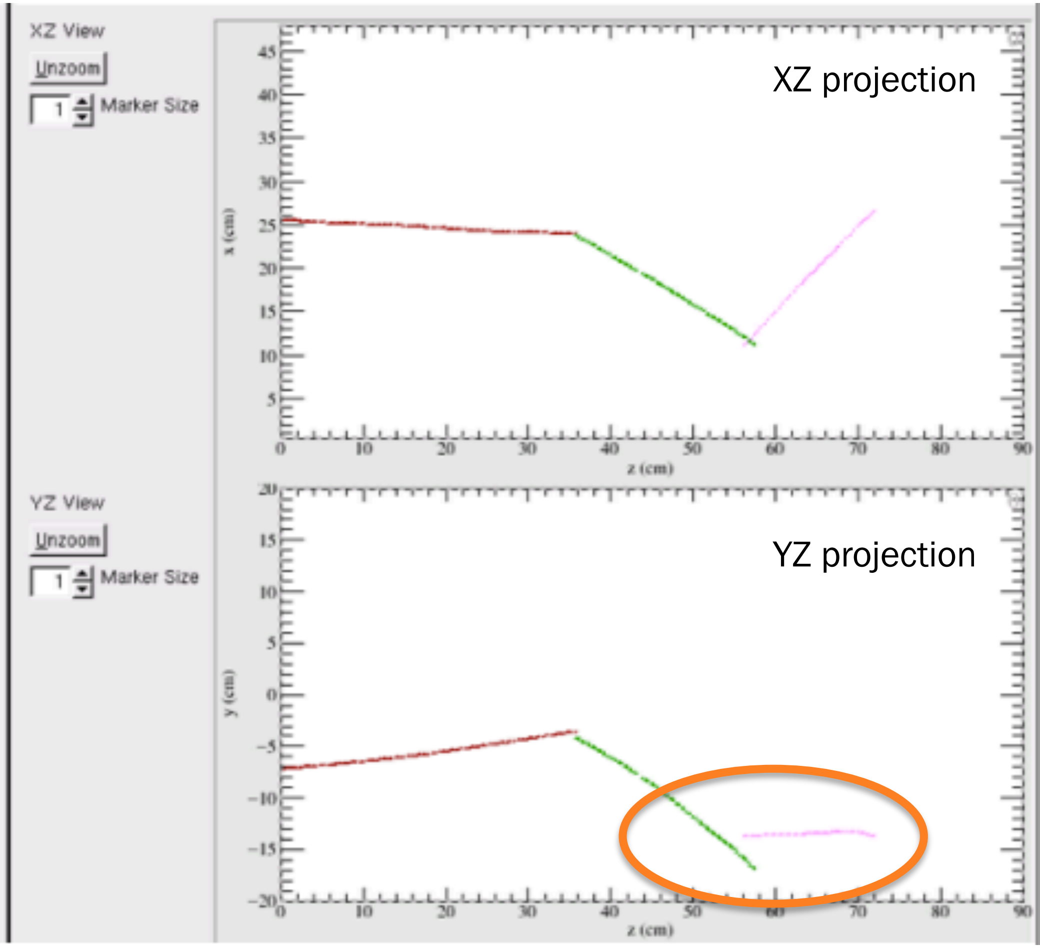


TRACK RECO: CLUSTER CRAWLER

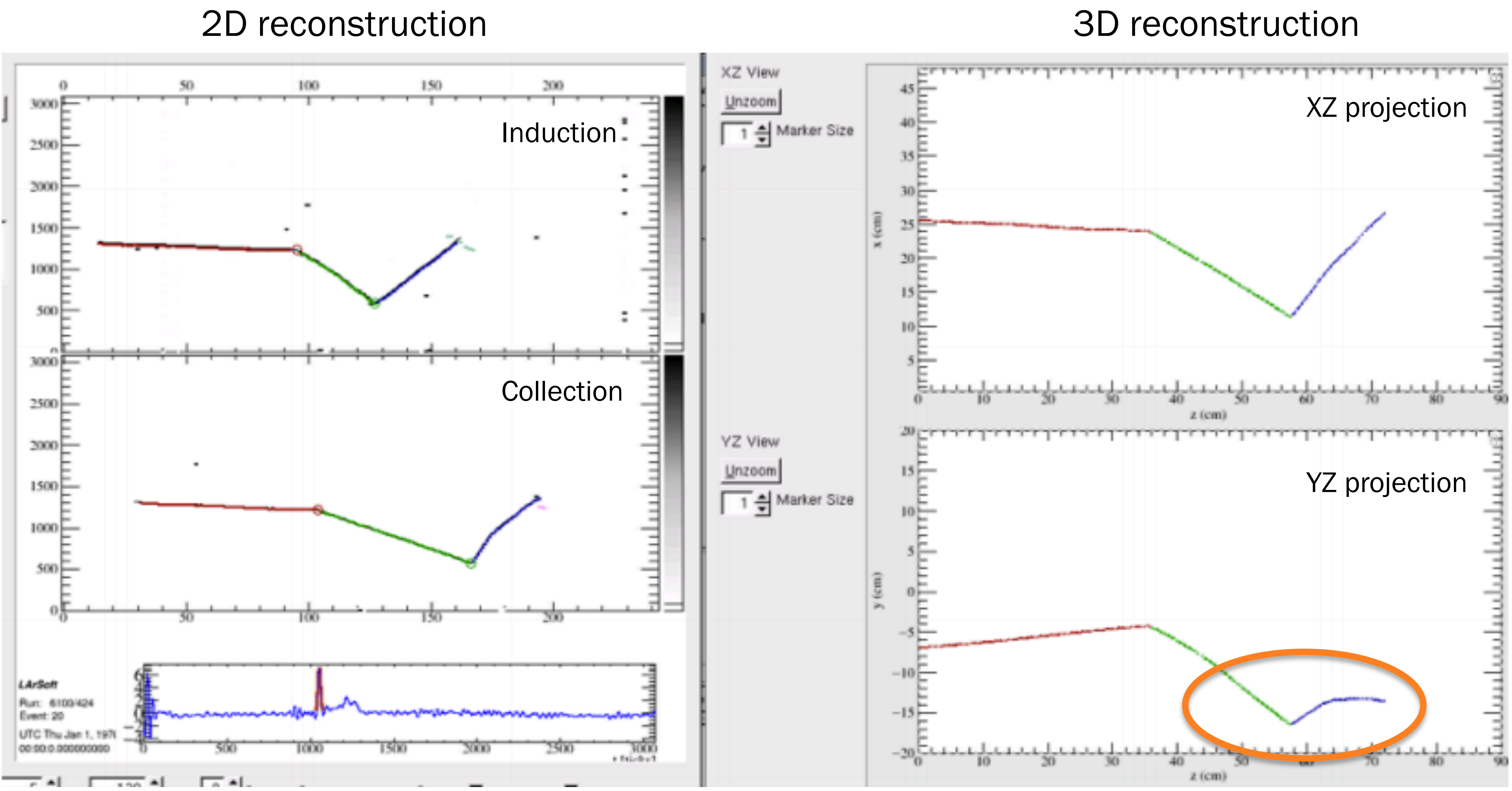
2D reconstruction



3D reconstruction



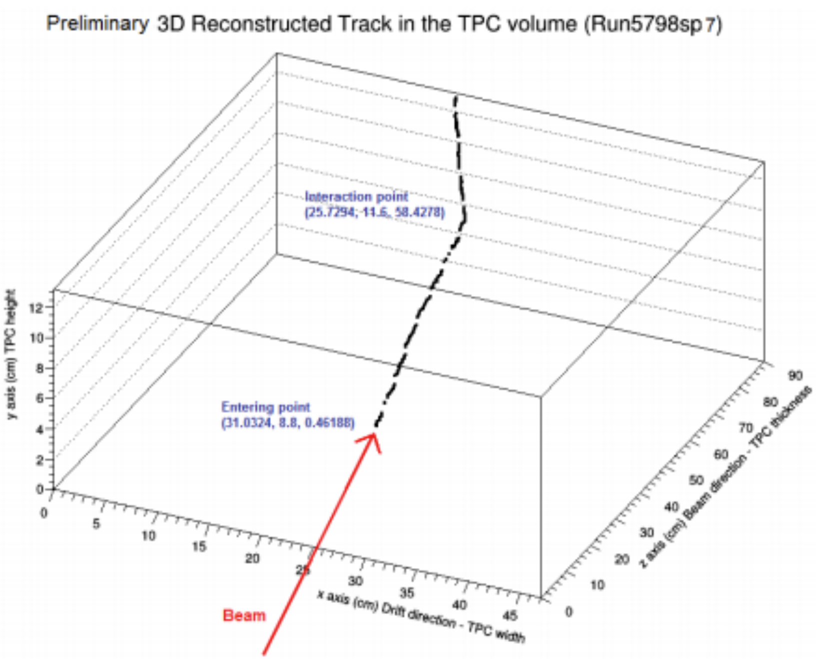
TRACK RECO: PMA VERTEXING

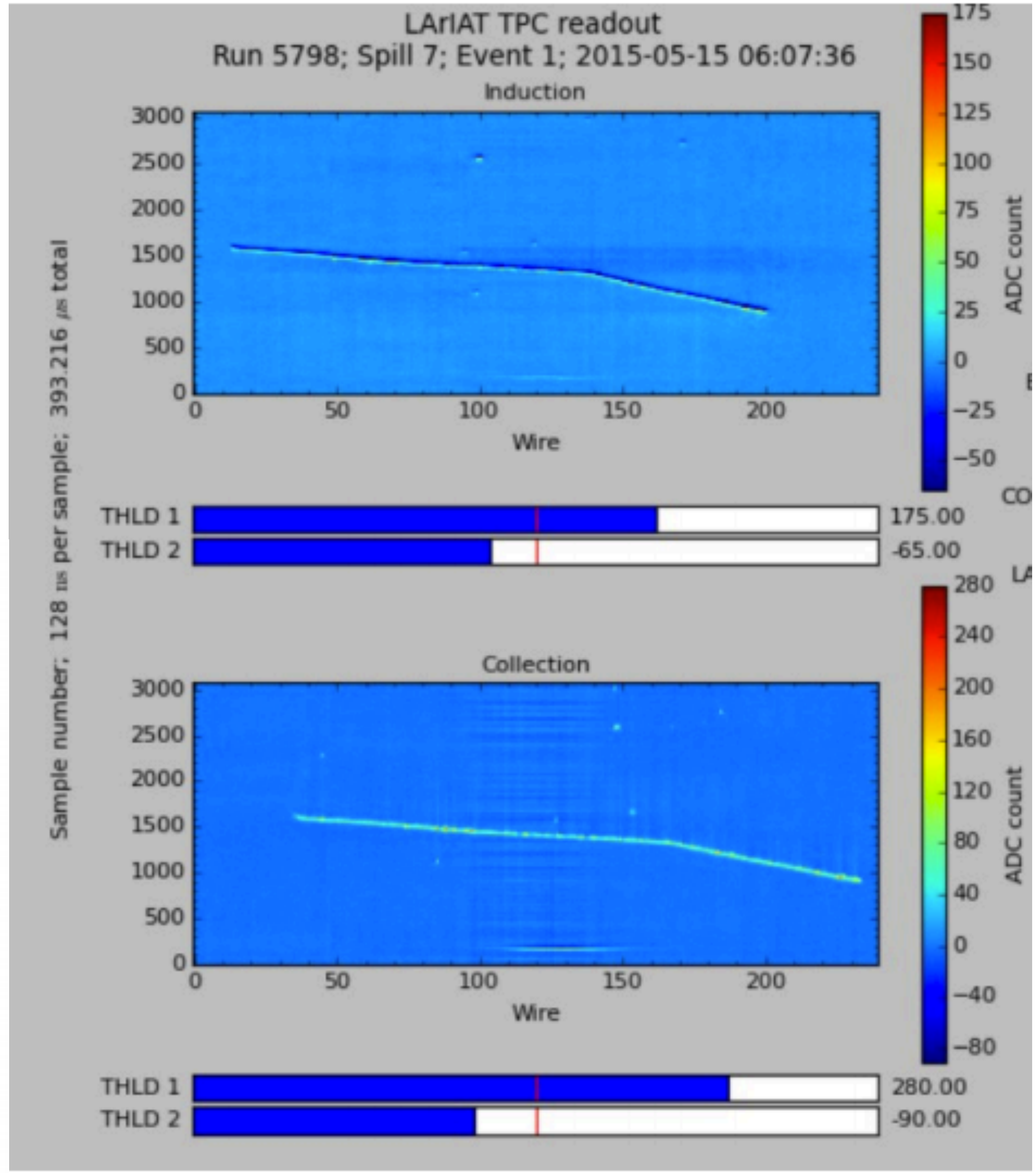


SMALL SCATTERING ANGLES

For events where the particle (usually pion) has undergone only a small scatter (< 20 degrees), track reconstruction sometimes makes a single cluster/track object

→ we would like to be able to reconstruct the interaction point; want ability to discriminate between hadronic interactions and pion decays or captures

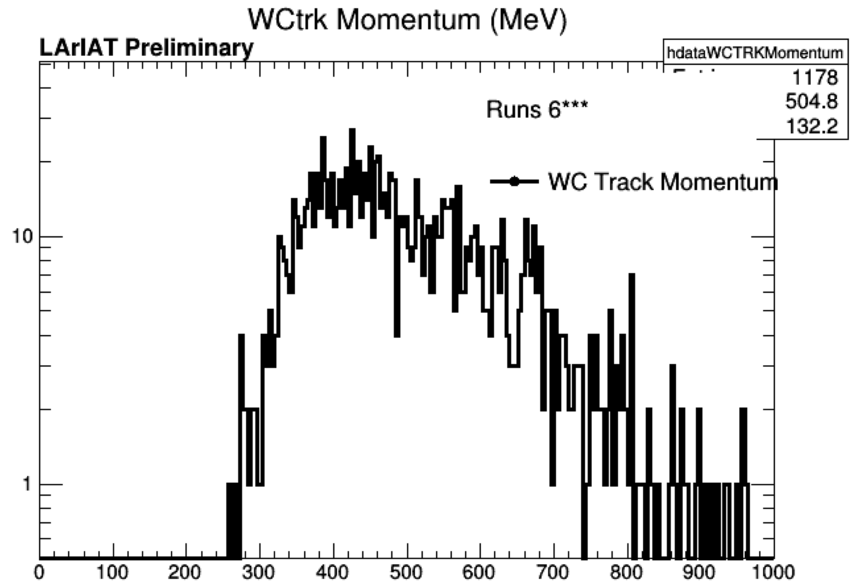


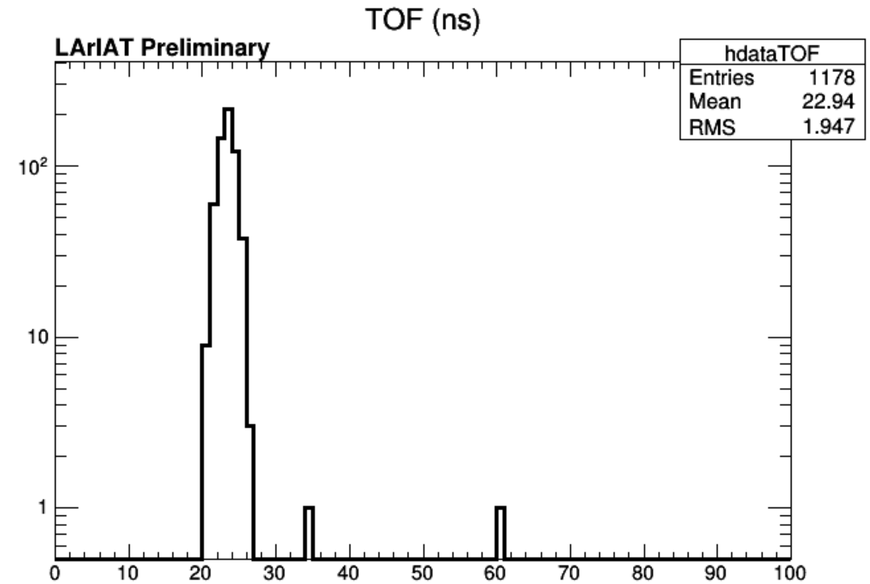


NON-TPC RECONSTRUCTION

LArIAT members have developed algorithms to reconstruct relevant beamline information

- Wire chamber tracks (momentum, projection to front face of TPC)
- Time-of-flight detectors (correlate TOF with wire chamber track)
- Aerogel Cherenkov detectors (in progress)
- Muon Range Stack (in progress)

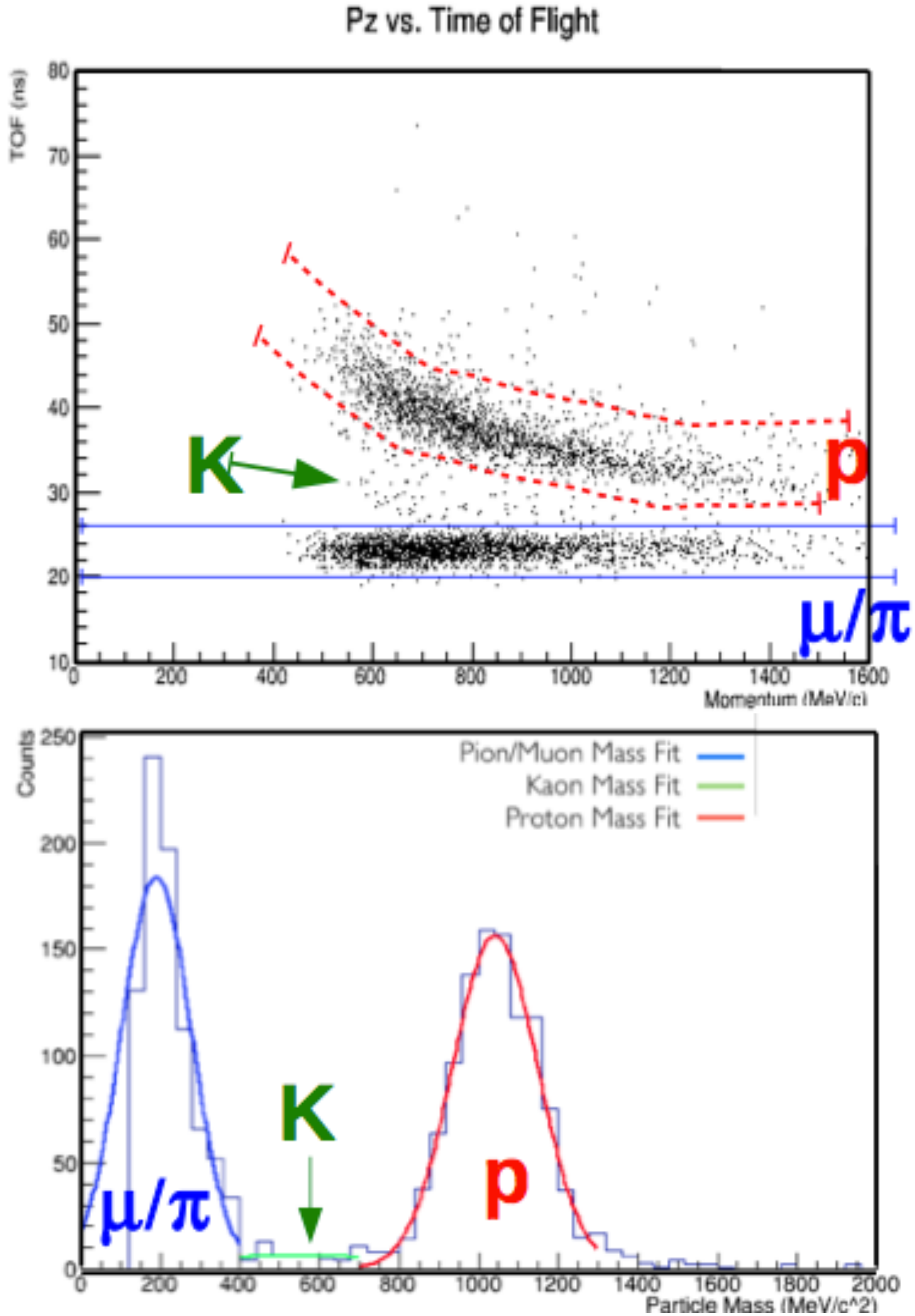




BEAMLINE PARTICLE ID

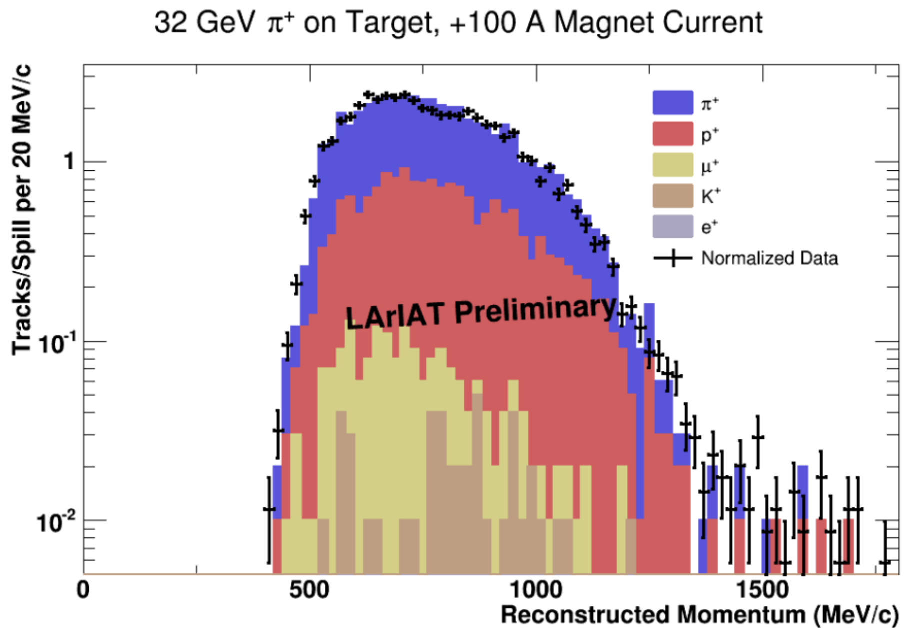
Make Particle ID hypothesis

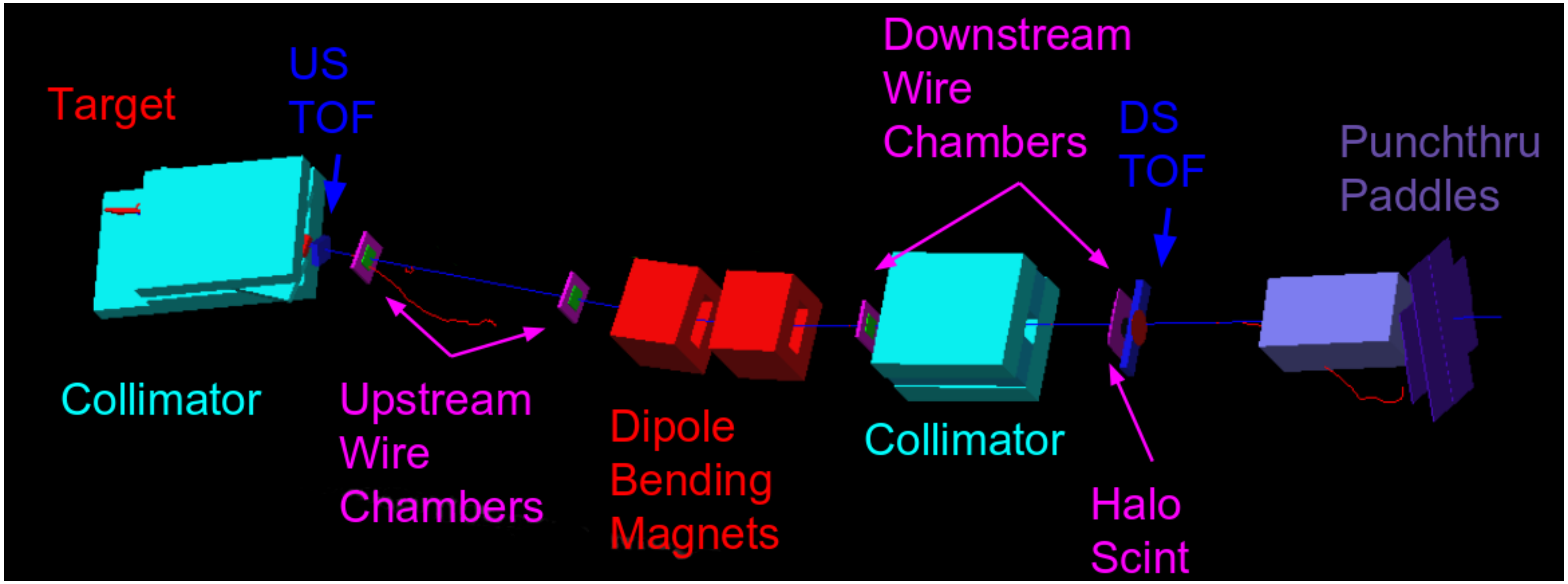
- TOF + MWPCs
- Currently working to add Aerogel Cherenkov and Muon Range Stack information for muon/pion separation



MONTE CARLO SIMULATIONS

- **G4Beamline:** beam propagated through all detectors to face of TPC
  - Particle species and energy spectra well-reproduced
  - Beam timing structure is lacking… therefore difficult to use these simulations for trigger efficiency studies, etc.
- **Geant4 particle gun:** dedicated TPC studies (no beamline information)





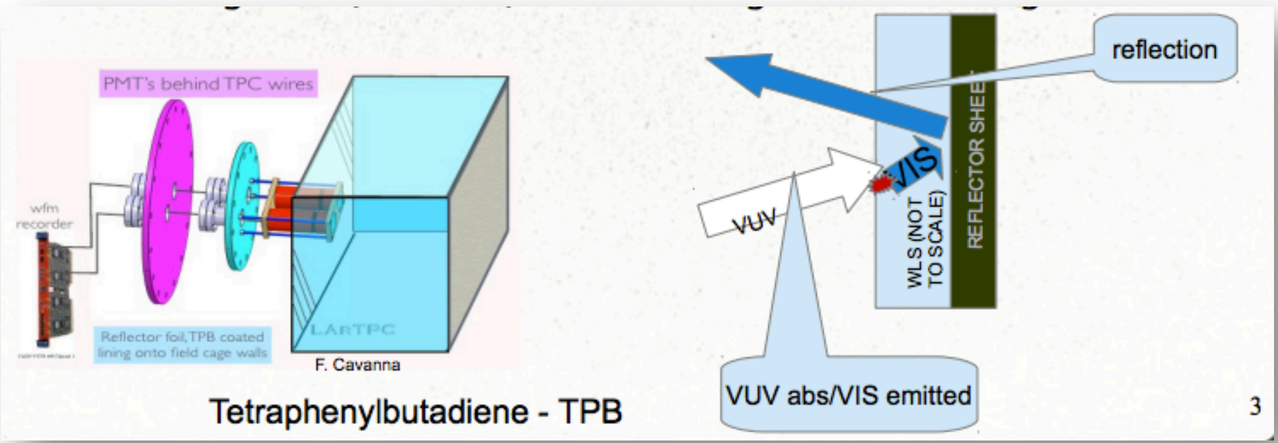
LIGHT COLLECTION SYSTEM SIMULATION

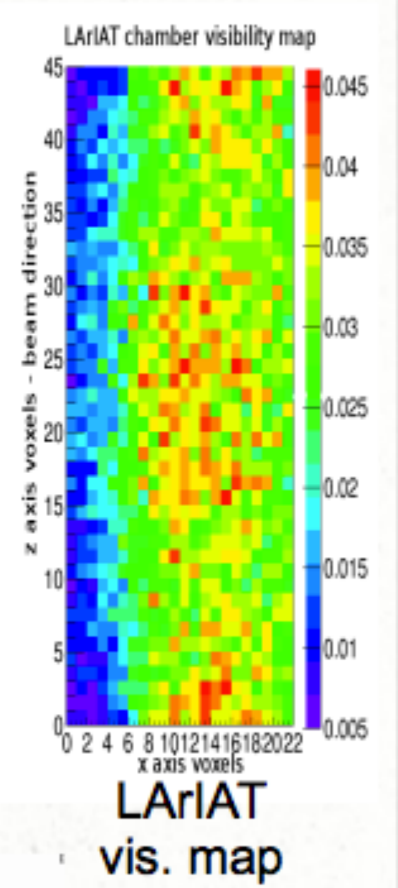
LAr scintillation light: ~40k pe's/MeV, 128n (VUV)

Goal: use scintillation light for calorimetry and PID

→ want uniform light collection and increased collection efficiency

This is the reason for using a reflector foil + TPB



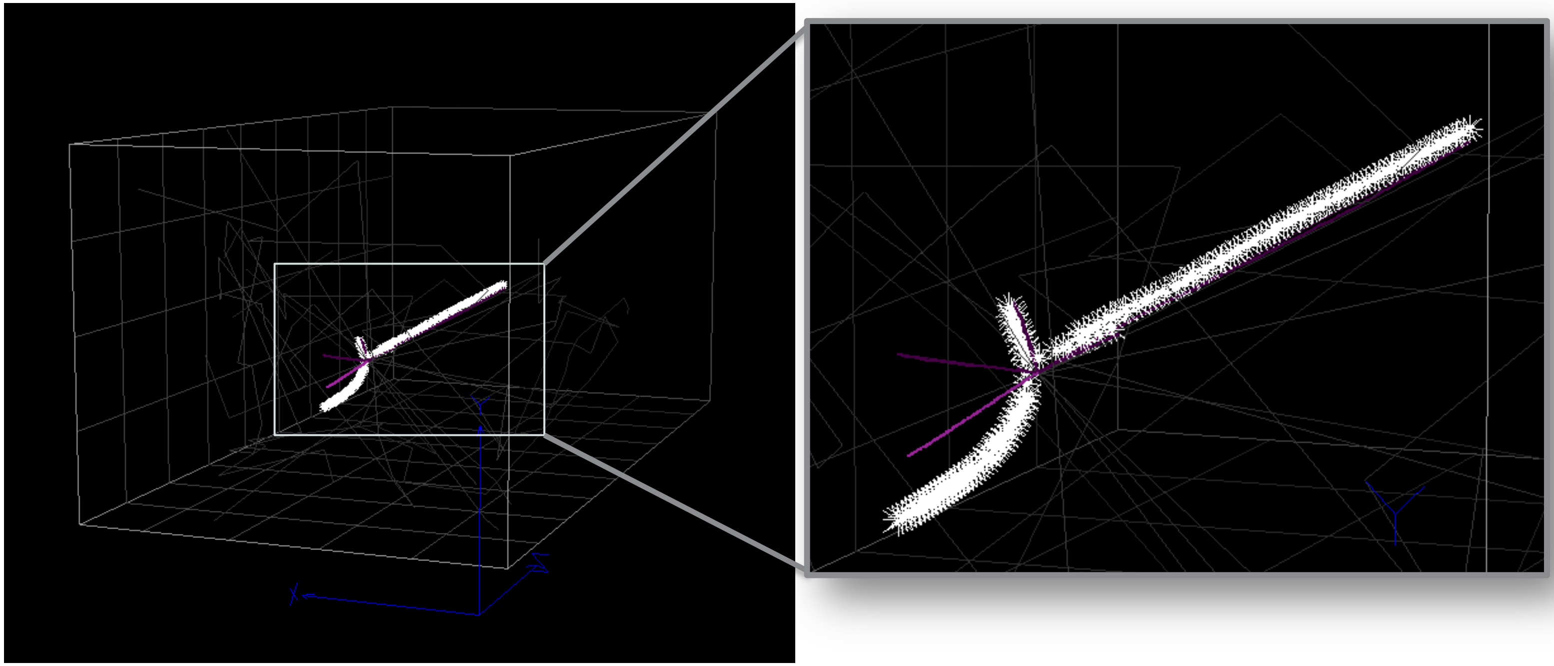


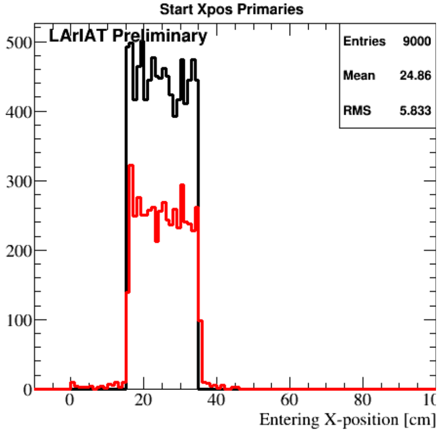
Simulations: chamber divided into voxels, build lookup library for fraction of photons reaching PMTs from each voxel.

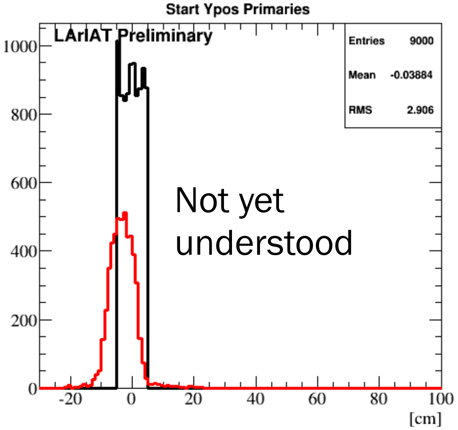
Real-world performance is being characterized now.

TPC TRACK RECONSTRUCTION PERFORMANCE

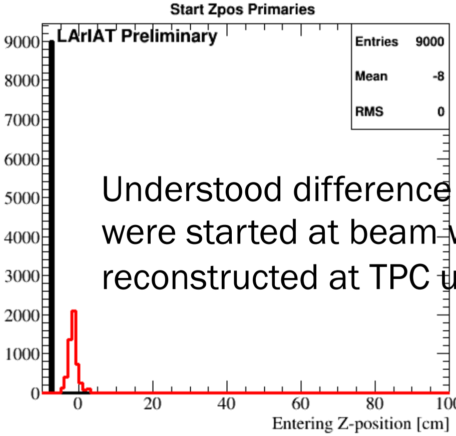
Using Geant4 particle gun, simulate charged pions entering front face of TPC







Not yet understood



Understood difference (all particles were started at beam window, but reconstructed at TPC upstream face)

SHOWER RECONSTRUCTION

Not fully working yet.

Promising work in Projection Matching Algorithm, but no performance plots for LArIAT yet.

CONCLUSIONS

- Most difficult part of getting reconstruction to work: modifying data structure to accommodate LArSoft expectation of what an event is

  Solved. We "sliced" our data into LArSoft-manageable chunks
- Deconvolution

  Works fairly well, especially since Tingjun tuned to LArIAT data
- Hit Finding

  Works well
- Clustering

  Tuning may improve cluster-splitting efficiency for small kinks

  Usually identifies reasonable clusters

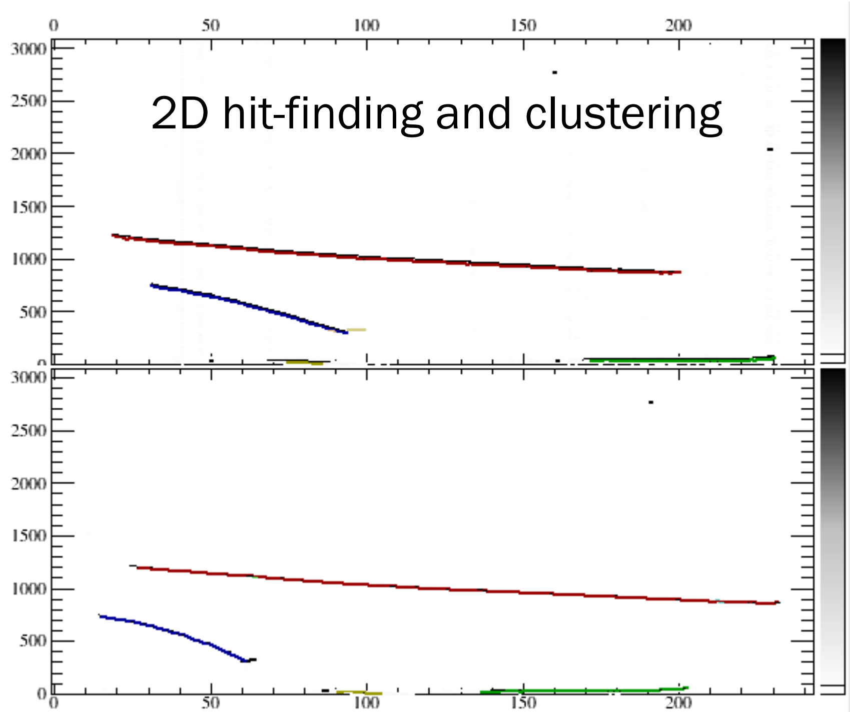
  Sometimes misses obvious tracks (rarely)
- Tracks & Showers

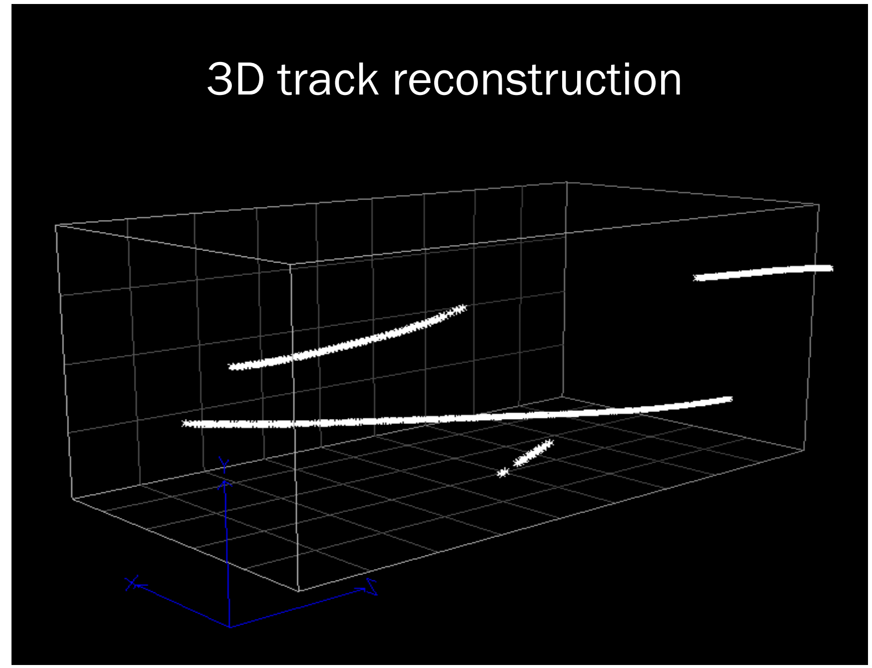
  PM tracking algorithm works very well, other tracking algorithms work ok

  Shower-finding runs without crashing, but not yet producing anything
- Calorimetry

  Working ok, but needs more tuning

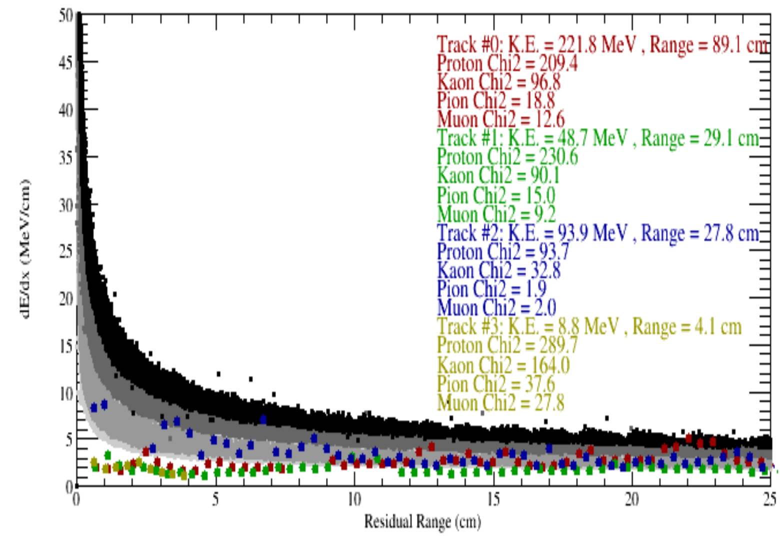
EXTRA SLIDES



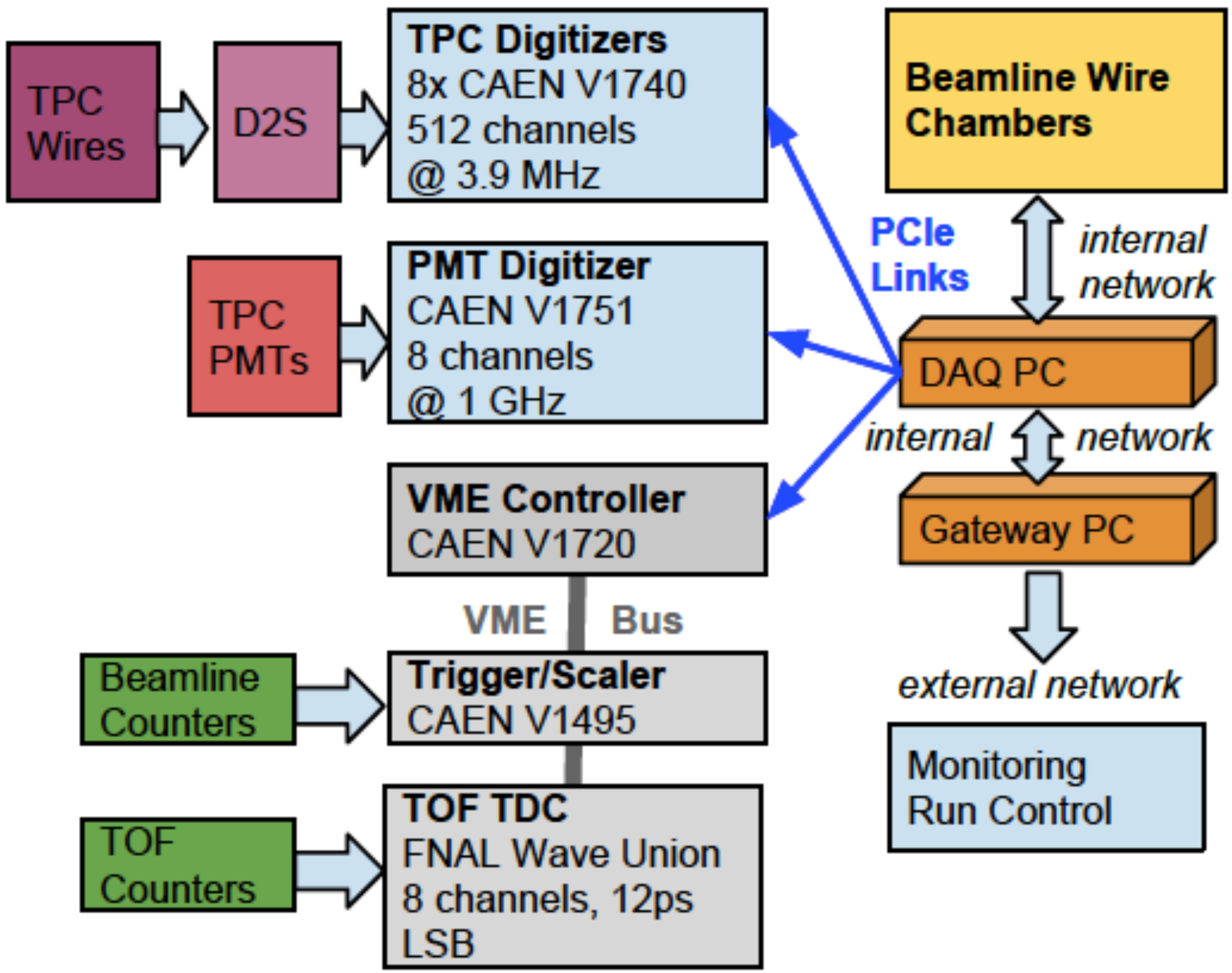


LArSoft modules tuned for LArIAT

- 2D hit-finding and clustering
- 3D track and shower reconstruction
- Track calorimetry and PID

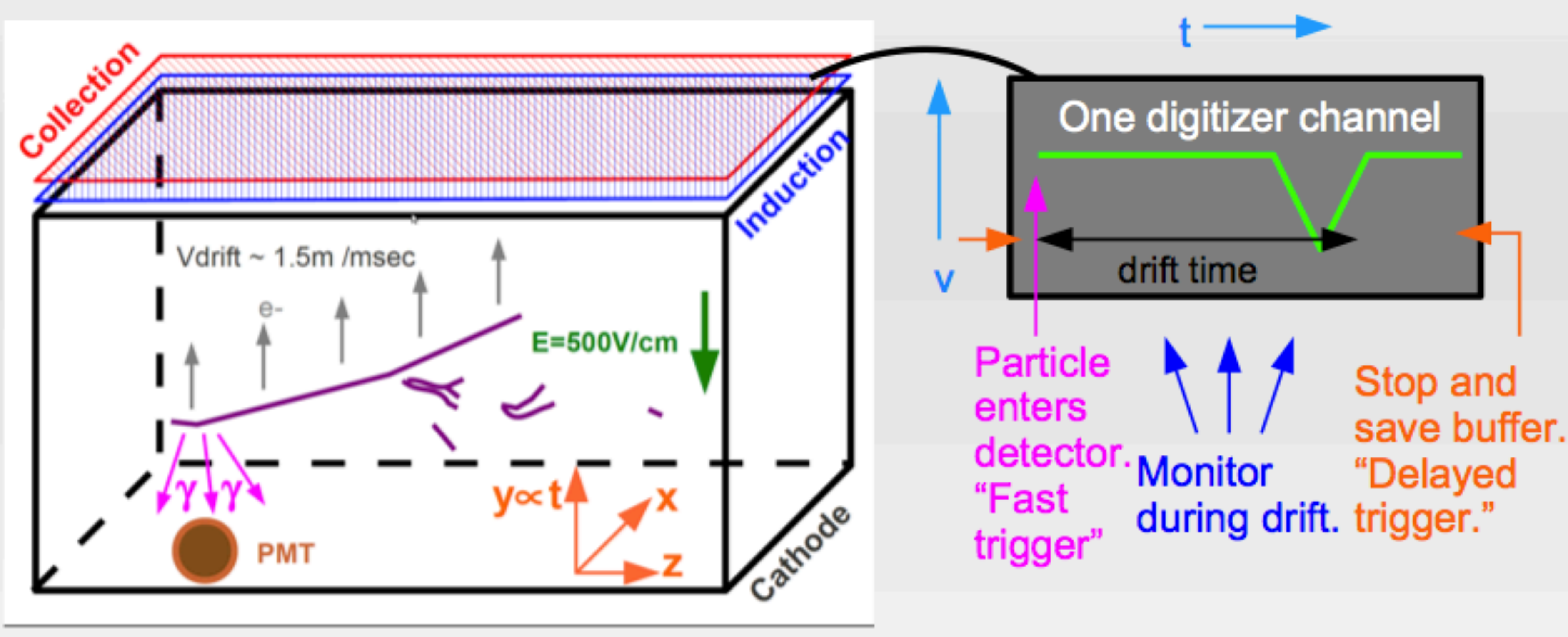


DATA FLOW



TPC Wires
D2S
TPC Digitizers
8x CAEN V1740
512 channels
@ 3.9 MHz
Beamline Wire Chambers
PCIe Links
internal network
TPC PMTs
PMT Digitizer
CAEN V1751
8 channels
@ 1 GHz
DAQ PC
internal
network
VME Controller
CAEN V1720
Gateway PC
VME
Bus
external network
Beamline Counters
Trigger/Scaler
CAEN V1495
Monitoring
Run Control
TOF Counters
TOF TDC
FNAL Wave Union
8 channels, 12ps
LSB

BASIC SITUATION



TPC digitizers read out @ ~4MHz to circular buffer

Cannot buffer entire 4 seconds of beam spill (10's of MB per channel...)

Readout is always "triggered" – must decide when to stop

Need to monitor pileup during drift time